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COST-BENEFIT ANALYSIS FOR USING LASER FLUOROSENSOR FOR DETECTING HEAVY OIL

FINAL REPORT

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16. Abstract (MAXIMUM 200 WORDS)
This report describes the methodology and results of a cost-benefit analysis for acquiring and implementing laser fluorosensor (LF) technology to assist the U.S. Coast Guard (USCG) in responding to heavy oil spills. Cost savings were estimated for four specific spill scenarios (three historical and one hypothetical), using an oil spill simulation model. Cost savings were also estimated using two statistics-based models applied to 115 heavy oil spills occurring over the past decade. Both approaches produced cost savings estimates that were roughly equivalent.

Acquisition, operation, and implementation costs were computed for four separate implementation options. Two options involved deploying a USCG-owned system on USCG aircraft, and two involved contracting for an LF capability. The potential annual cost savings were compared against projected implementation costs. Interim implementation options are discussed and recommendations for further investigation are provided.

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heavy oil spills; submerged oil; SIMAP; statistical analysis; historical oil spill scenario; cost-benefit analysis; implementation; aircraft; laser fluorosensor; acquisition; OSRCEAT

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EXECUTIVE SUMMARY

Oil spills involving heavy oil present unique problems to spill responders because of the difficulties involved in tracking and recovering heavy oils and the damages that can result if spilled oil affects sensitive environments. The laser fluorosensor (LF) remote sensing technology shows promise in allowing spill responders to detect and track heavy oil spills and to improve chances of successfully recovering spilled oil before it impacts sensitive resources. However, as with any major systems acquisition, the U.S. Coast Guard (USCG) must carefully weigh the long-term investment (system costs) against the benefits (cost savings). This study accomplishes this careful weighing by means of a cost-benefit analysis. An interdisciplinary project team consisting of Potomac Management Group, Inc. (PMG), Environmental Research Consulting (ERC), and Applied Science Associates, Inc. (ASA) performed the work.

First, ERC compiled heavy oil spill statistics to determine current trends in heavy oil spills, and to assess the relative magnitude of the heavy oil problem in comparison to the overall oil pollution problem. Next, ERC examined selected major heavy oil spills over the past decade to assess what the cumulative impact might have been had LF technology been available for use in the response to these spills.

The project team then considered 15 major heavy oil spills that had occurred in the past. From these, the team chose four of these spills for the next phase of the study: a scenario-based cost-savings analysis (specifically, (1) the T/B BOUCHARD 155 spill in Tampa Bay, in August, 1993; (2) the T/V COMMAND spill off Half-Moon Bay, CA, in September 1998; (3) the PEPCO Pipeline spill in the Patuxent River, MD, in April 2000; and (4) the T/V ATHOS I spill in the Delaware River, in November 2004).

This analysis involved simulating each spill using an oil spill simulation model (SIMAP) developed by Applied Science Associates, and using the results of each simulation to predict the cost savings that might have been realized had LF technology been used at specific times (2, 12, 24, and 72 hours) after a spill. During this modeling analysis, the project team determined that the LF technology would not have influenced the outcome of the T/V ATHOS I spill. Accordingly, the project team modeled a fourth spill, involving a hypothetical oil spill in the Strait of Juan de Fuca, and analyzed this spill using the same procedure as outlined above.

Results of the LF scenario-based cost-savings analysis for the T/B BOUCHARD 155, the PEPCO pipeline, and the Strait of Juan de Fuca spills suggest that each large spill might result in up to \$10.7M savings in response costs, up to \$0.6M savings in Natural Resource Damage (NRD) costs, and potentially as much as \$4.0M in socioeconomic costs. The savings associated with the T/V COMMAND spill were negligible. Taken together, these results suggest a representative cost savings for a large heavy oil spill of \$5M to \$15M. A conservative estimate on the frequency of occurrence of heavy oil spills of this nature and magnitude is perhaps once every five years. These results suggest a potential annual cost savings of \$1.0M to \$3.0M per year in all cost categories. For response costs alone, the savings are likely to be \$0.5M to \$2.0M per year.

In addition to the scenario-based analysis, ERC performed a statistics-based model analysis on 115 heavy oil spills occurring between 1995 and 2004, using two models developed by ERC. The first of these models provides relative damage and cost estimates for different spill types; the

second compares costs to benefits. ERC used these models to estimate the potential cost-savings associated with implementing an LF capability at 2, 12, 24, and 72 hours after a spill occurred. If the LF capability were only employed on 20 percent of the 115 spills considered, the first model predicts that approximately $10M per year would be saved if LF technology is employed within two hours, $5M if it is employed within 24 hours, and $1.5M if it is employed within 72 hours. The second model suggests a cost savings of approximately $8M per year in all cost categories for the 12-hour LF insertion on 20 percent of the spills.

Taken together, the two cost savings predictions suggest an annual cost savings associated with the LF capability of $1M to $10M per year. These figures depend on when the LF capability comes into play, and on the enhanced effectiveness (greater percent of oil recovered) it provides. Assuming that the LF capability would likely arrive on-scene between 12 and 24 hours after notification of the spill, for most spills, an annual cost savings of $5M to $8M would be expected including response costs, environmental costs and socioeconomic costs. For response costs alone, an annual savings of $1M to $2M is expected.

Implementation costs for the LF capability range from roughly $0.3M to $0.5M per year assuming implementation on 2 to 4 aircraft. The project team analyzed four specific implementation options: two involved implementation on CG aircraft; one involved contracting for the LF capability; and the last involved implementing the LF technology on aircraft-of-opportunity. Implementation costs depend on the implementation option chosen. Implementation costs included sensor system acquisition and installation cost, aircraft costs, system maintenance cost, personnel costs and training costs. The most expensive options involve implementing a USCG-owned and operated sensor system on a USCG fixed-wing aircraft or helicopter. This option would cost approximately $0.5M per year. Although more costly, it would provide an increased likelihood of availability in the event of a major heavy oil spill. The least expensive options involve using another agency's sensor system and aircraft, or mounting a USCG sensor system on a contracted aircraft-of-opportunity. These options would cost approximately $0.3M per year. Overall, the model-based cost-benefit analysis undertaken in this study indicates that costs and benefits for the LF are roughly equal when viewed on an annual basis.

In conclusion, the study indicates that acquiring a long-term LF capability within the USCG is not warranted on the basis of projected operational cost-savings alone at this time. However, short-term acquisition of a limited LF capability under contract would provide a system capable of responding to heavy oil spills that could be used to further investigate the performance and utility of LF technology. At the same time, the USCG should continue to monitor and support developments in LF technology to make LF sensing systems smaller and easier to operate, and overcome the current limitation in water depth penetration (one to two meters) to allow detection of oil resting on the bottom. In addition, it is recommended that other potential applications of the LF (such as oil pollution surveillance and enforcement; detection of hazardous chemical spills; search and rescue of a sinking or submerged vessel; and detection of chemical and biological agents) be investigated in order to determine the benefits that might accrue from these applications.

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LIST OF ACRONYMS

AC	Aircraft
AIREYE	(designation of remote sensing system in CG H-25 aircraft)
AOSS	Airborne Oil Spill Surveillance System
ASA	Applied Science Associates
bbl	Barrel
BOSCEM	Basic Oil Spill Cost Estimation Model
CASPER	C-130 Airborne Sensor w/Palletized Electronic Reconnaissance
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CGAS	Coast Guard Air Station
CONUS	Continental United States
EDRC	Effective Daily Recovery Capacity
EG&G	Edgerton, Germeshausen and Grier Engineers
ERC	Environmental Research Consulting
FLIR	Forward-Looking Infrared (cameras)
FLS-S	Fluorescent Lidar Spectrometer-Shipboard System
FLS-AM	Fluorescent Lidar Spectrometer – Airborne M-Model
FLS-AU	Fluorescent Lidar Spectrometer – Airborne U-Model
FOSC	Federal On-Scene Coordinator
GRP	Geographic Response Plan
HEA	Habitat Equivalency Analysis
ICS	Incident Command System
IR	Infra-Red
ISAR	Inverted Synthetic Aperture Radar
K	Thousand
km	Kilometers
LF	Laser Fluorosensor
M	Million
m	Meters
MARPOL	International Convention for the Prevention of Pollution from Ships
MMS	Minerals Management Service
MSO	Marine Safety Office
MWR	Microwave Radiometer
NASA	National Aeronautics and Space Administration
NF	No Fluorosensor
NOAA	National Oceanic and Atmospheric Administration
NM or nmi	Nautical Mile
NRD	Natural Resource Damage
NRDA	Natural Resource Damage Assessment
NRDAM/CME	Natural Resource Damage Assessment Model for Coastal and Marine Environment
OHMSETT	Oil and Hazardous Materials Simulated Environmental Test Tank
OSC	On-Scene Coordinator
OSRCEAT	Oil Spill Response Cost-Effectiveness Analytical Tool

LIST OF ACRONYMS (CONTINUED)

OPA 90	Oil Pollution Act of 1990
OSRV	Oil Spill Response Vessel
PMG	Potomac Management Group
POC	Particulate Oceanographic Lidar
POLREPS	Pollution Reports
R&DC	Research and Development Center
RDT&E	Research, Development, Test & Evaluation
ROM	Rough Order of Magnitude
RP	Responsible Party
SAR	Synthetic Aperture Radar
SESI	Science and Engineering Services, Inc.
SIMAP	Spill Impact Model Analysis Package
SLAR	Side-Looking Airborne Radar
SLEAF	Scanning Laser Environmental Airborne Fluorosensor
SSC	Scientific Support Coordinator
UBTL	Ultraviolet Biological Trigger Lidar
U.S.	United States
USCG	United States Coast Guard
UV	Ultraviolet
WDOE	Washington State Department of Ecology

1. BACKGROUND

Oil spills involving heavy oil present unique problems to spill responders because of the difficulties involved in tracking and recovering heavy oils and the damages that can result if spilled oil affects sensitive environments. This section describes the nature of the heavy oil problem, and the potential value of using laser fluorosensor (LF) technology in responding to spills of heavy oil.

1.1 The Problem: Heavy Oil Detection

Preliminary research on the significance of heavy oil spills shows that heavy oils are the fourth largest category of oils spilled, accounting for 2.3 million gallons, or 10 percent, of the total oil spilled in the last decade. Heavy oils include No. 5, No. 6, and heavier fuel oils, as well as bunker fuels, and heavier crude oils. There have been 115 heavy oil spills of at least 500 gallons in U.S. navigable waters within the last decade, with an average spill size of just over 20,000 gallons (Environmental Research Consulting (ERC, 2006)). Although heavy oil spills are less frequent than are those involving other types of oil, they tend to be more problematic because heavy oils are often difficult to locate and recover and can severely impact natural environments. In addition, heavy oils can sink below the surface and become undetectable by either visual observation or sensing device.

Without timely and accurate spill information, appropriate countermeasures and cleanup assets cannot be deployed effectively. As a result, the overall cost of the response to a heavy oil spill, and the overall environmental impact, can be much greater than would otherwise be the case.

In general, it is advantageous from the perspective of minimizing the impact and cost of an oil spill to act strategically—that is, to "keep ahead of the oil" versus chase after it—because spilled oil can be spread rapidly by forces of tide, current, and wind. This strategic approach involves effectively deflecting oil away from sensitive areas and reducing overall response time. With current technology, this approach is difficult to execute. However, a remote sensing tool able to identify, map, and track oil on or below the surface, even in conditions of reduced visibility, would go a long way toward making a strategic approach to heavy oil spills possible.

1.2 Heavy Oil Detection Sensing Technology

The LF is an emerging technology that enables detecting, identifying, and tracking oil spills in situations of decreased visibility (for example, darkness and haze). It is also capable of detecting oil in situations where the oil has become neutrally or negatively buoyant so that it either remains just below the surface or sinks. LF also allows positive identification and mapping of the spill in situations where current oil spill sensors (particularly Side-Looking Airborne Radar (SLAR) and Forward-Looking Infrared (FLIR) cameras) cannot discriminate between spilled oil and the surrounding environment (for example, oil in marsh areas or in ice). Experience in past spills indicates that all three of these situations might occur in spills involving heavy oils.

The LF is the only oil spill sensor that provides conclusive identification of oil within natural backgrounds in the marine environment, including water; various types of shoreline; and snow and ice (Brown and Fingas, 2003 and Lissauer and Robe, 2004 and 2005). The sensor excites oil

on and below the surface, using an ultraviolet (UV) laser. The oil fluoresces in the visible spectrum with a spectral signature unique to petroleum compounds. Other materials in the marine environment do not fluoresce with this signature, thereby reducing false positives. This reduction of false positives allows the data from other oil sensors, when used in combination with the LF, to be correctly interpreted more often. Because the sensor actively excites the oil with the laser, it can detect oil in darkness, as well as in conditions of low visibility (except heavy fog). It can also detect oil at depths of several meters in clear water; and at depths of one to two meters in most ocean, estuary, and river environments.

LF systems can be either profiling or scanning systems. Profiling systems are stationary and detect oil along a single track directly below the aircraft as the aircraft moves over the water. The scanning systems sweep back and forth to cover a wider swath (e.g., 200 meters wide) on either side of the aircraft. The tradeoff is that although scanning systems cover a wider area, they are more complex and expensive than the profiling systems.

Profiling versions of the LF technology have been developed by both government agencies and private companies. Three systems were tested for oil detection capability by the United States Coast Guard (USCG) Research and Development Center (R&DC) at the Minerals Management Service's Oil and Hazardous Materials Simulated Environmental Test Tank facility (OHMSETT), as reported by Fant and Hansen (2005 and 2006). A scanning system (the Scanning Laser Environmental Airborne Fluorosensor—SLEAF) has been developed and tested by Environment Canada. The SLEAF system can detect oil within a track width of 200 meters at an altitude of 600 meters. However, because it is a scanning sensor, it is not capable of sampling all points within the track, such that oil in small concentrations (for example, individual tar balls) might be missed.

The disadvantages of the LF at its current state of development are its size and complexity and the cost of acquiring, implementing, and maintaining the system. The size and weight of the sensor itself are modest—1 cubic foot, approximately 20 pounds, depending on the system; however, the supporting equipment for the sensor makes the entire system fairly bulky, such that it requires a dedicated fixed-wing aircraft, with significant modifications to the aircraft. The cost of the sensor itself is $100K and up but the cost of the entire system is greater than $500K (Lissauer and Robe, 2005). In addition, operating the system and interpreting the data requires significant up-front training.

Table 1 summarizes the advantages and disadvantages of the LF system.

Table 1. Advantages and disadvantages of the LF system.

Advantages	Disadvantages
• Provides conclusive identification of oil in marine environment • Provides a day/night surveillance capability • Can detect oil to a depth of 1-2 meters • Can be used with other oil sensors to eliminate false positives, increasing the value of other sensors • Can be used as a profiling tool (with some scanning capability)	• Limited in fog and other conditions where particulates in air interfere with laser • Complete system is bulky, requiring dedicated fixed-wing aircraft • Cost of the complete system exceeds $500K • Operation of system requires substantial training • No way to determine quantity • Tarballs or isolated patches of oil may be missed

2. STUDY PURPOSE AND SCOPE

As described in Section 1, the availability of an LF oil spill sensing capability could be beneficial toward making USCG responses to heavy oil spills more effective and efficient. However, as with any major system acquisition, the USCG must carefully weigh the long-term investment (system costs) against the benefits (cost savings). This section summarizes the role of this study in accomplishing a cost-benefit analysis toward this end.

2.1 Need for the Study

LF technology shows promise in allowing spill responders to detect and track heavy oil spills, and to improve the chances of successfully deflecting or recovering oil before it impacts sensitive resources. However, an LF system is expensive to purchase and to install aboard an airborne platform, and requires a significant long-term investment in logistics support, maintenance and training. Thus, the projected costs versus benefits of system acquisition and implementation must be carefully considered. The purpose of this study is to investigate and analyze the costs versus benefits of providing an LF capability to the USCG. It should be noted that although this report focuses on response to heavy oil spills, the LF has applications in detecting, identifying and mapping lighter oils in decreased visibility conditions and situations where it is difficult to discriminate oil from other materials in the marine environment.

2.2 Components of the Study

The project team carried out the LF cost-benefit analysis in four phases. The first phase involved an Opportunity Analysis (described in Section 3 of this report) that investigated the type and number of spills that involve heavy oil; the frequency of these spills; and the response costs and damage costs associated with them (including both natural resource and socioeconomic damages). This information provided insight into the impact and importance of heavy oil spills in relation to the impact and importance of other spills. This phase of the study also provided

statistical data that were subsequently used in a statistics-based benefit analysis for the LF capability described in Section 5 of this report. The data for this portion of the study were derived from the Environmental Research Consulting (ERC) Database (cited as ERC, 2006), which has been compiled over the past 15 years, and has supported a number of oil pollution strategic studies and modeling efforts.

The second phase of the study, Historical Case Studies, involved a closer look at a number of major heavy oil spills to determine the characteristics of those spills and whether the availability of the LF technology might have made a difference in the response effort. A key objective in this phase was identifying several spills that could be used in a scenario-based analysis of the benefits afforded by a heavy oil detection capability.

During the third phase, Scenario-Based Analysis, five specific heavy oil spills were analyzed in detail to determine the cost savings associated with employing an LF capability at different points in the response effort. This analysis, using a numerical oil spill simulation model, provided a rough estimate of the annual cost savings that could be realized by having a heavy oil detection capability available.

The fourth phase of the study, Airborne Platform Analysis, involved a detailed assessment of the cost associated with providing an LF capability to the USCG for responding to oil spills anywhere in the Continental United States (CONUS) and Alaska within 12 hours of notification. This analysis investigated and determined the general characteristics of current LF systems, and determined the costs associated with four implementation options: (1) installation of a USCG owned and operated system on a USCG fixed-wing aircraft; (2) installation of a USCG owned and operated system on a USCG helicopter; (3) installation of a USCG owned and operated system on an aircraft-of-opportunity; and (4) contracting for an LF capability from another agency. For each option, the system acquisition and installation costs were determined, along with the costs of the airborne platform, personnel, maintenance, and training necessary to provide operational capability over a ten-year system lifetime. This phase of the study (described in Section 6 of this report) provided estimates of the annual cost of the LF system, and compared those costs with the annual cost savings projected to be derived from using the system, as calculated in the cost-savings analysis. These four phases of the study resulted in separate reports submitted to the USCG R&DC. These reports are archived and available from the R&DC (Potomac Management Group (PMG), 2006a and b).

3. OPPORTUNITY ANALYSIS FOR USE OF THE LF

Heavy oil spills account for only a portion of the oil spill incidents occurring in U.S. waters. Before making a major investment focusing on responding to heavy oil spills, it is important to understand the significance of these spills in relation to the larger oil pollution problem. Key parameters include the number and frequency of heavy oil spills, volume of the oil spilled, and costs associated with these spills, including response costs, natural resource damage (NRD) costs, and socioeconomic damage costs. This section addresses these parameters and offers insight into the potential impact of LF technology in oil spill response.

3.1 Trends in Heavy Oil Spillage

An analysis of oil spillage on navigable waters of the U.S. for the last decade (1995-2004) reveals that a total of nearly 25 million gallons of oil have been spilled in over 2,000 incidents

involving at least 500 gallons (ERC, 2006). There is an overall downward trend in both annual spill numbers and volume. During the first half of the last decade (1995-1999), an average of 3.5 million gallons was spilled annually in 259 incidents involving at least 500 gallons. During the latter half (2000-2004), annual spillage averaged 1.5 million gallons per year, in 156 incidents involving at least 500 gallons.

Heavy oils (including No. 5 fuel, No. 6 fuel, heavier fuels, bunker fuels, and heavy crude) are the fourth largest category of oils spilled, with 2.3 million gallons, or 10 percent of the total oil spilled in the last decade. There have been 115 heavy oil spills of at least 500 gallons in U.S. navigable waters in this time period (1995-2004) with an average spill size of just over 20,000 gallons. These spills are listed in Appendix A. The overall trends in the number of heavy oil spills, volume of the oil spilled, and the relative proportion of spills of heavy oil to spills of other oil are illustrated in Figure 1 and Figure 2. Data on heavy oil spilled between 1995-2004, for spills of 500 gallons or more, are summarized in Table 2.

With heavy oil spills, as with all spills, the average annual volume of spillage has decreased since the first half of the decade, from an average of 348,000 gallons annually to 123,000 gallons. The number of heavy oil spills occurring each year has decreased as well, from an average of 16 spills of at least 500 gallons per year during 1995-1999, to an average of seven spills per year of this magnitude during 2000-2004 per year.

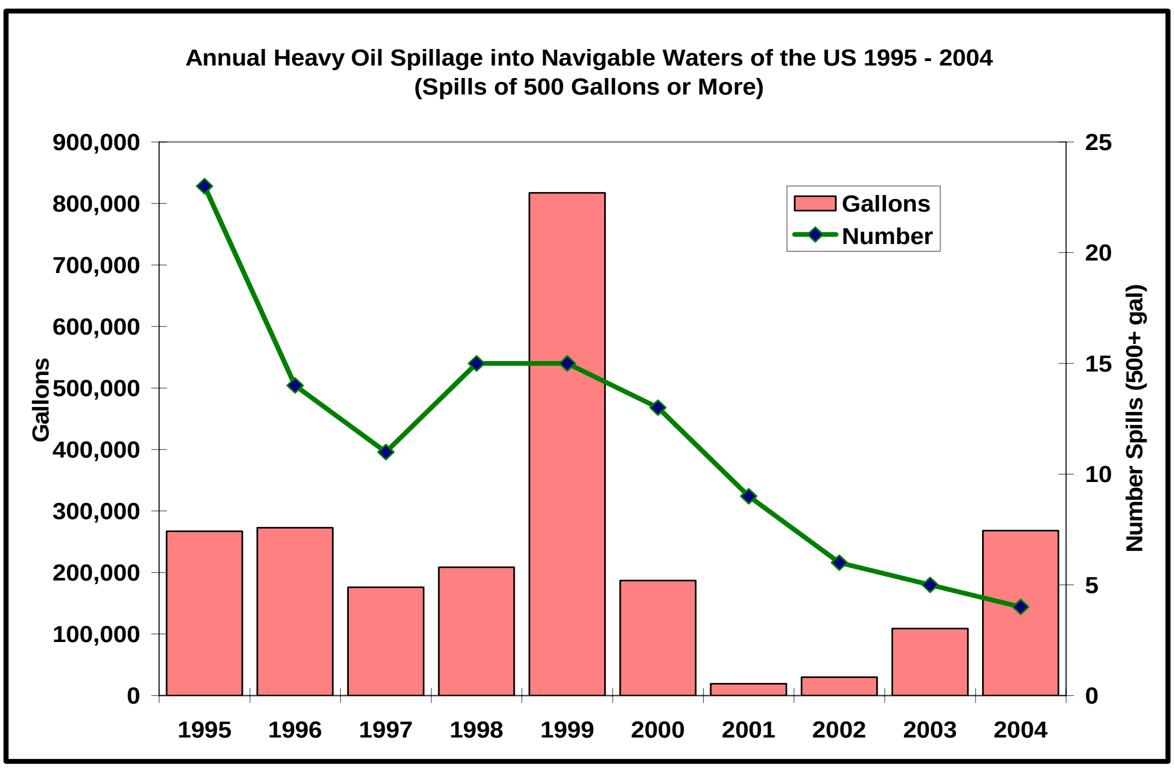

Figure 1. Number and volume of heavy oil spills into U.S. navigable waters 1995-2004.

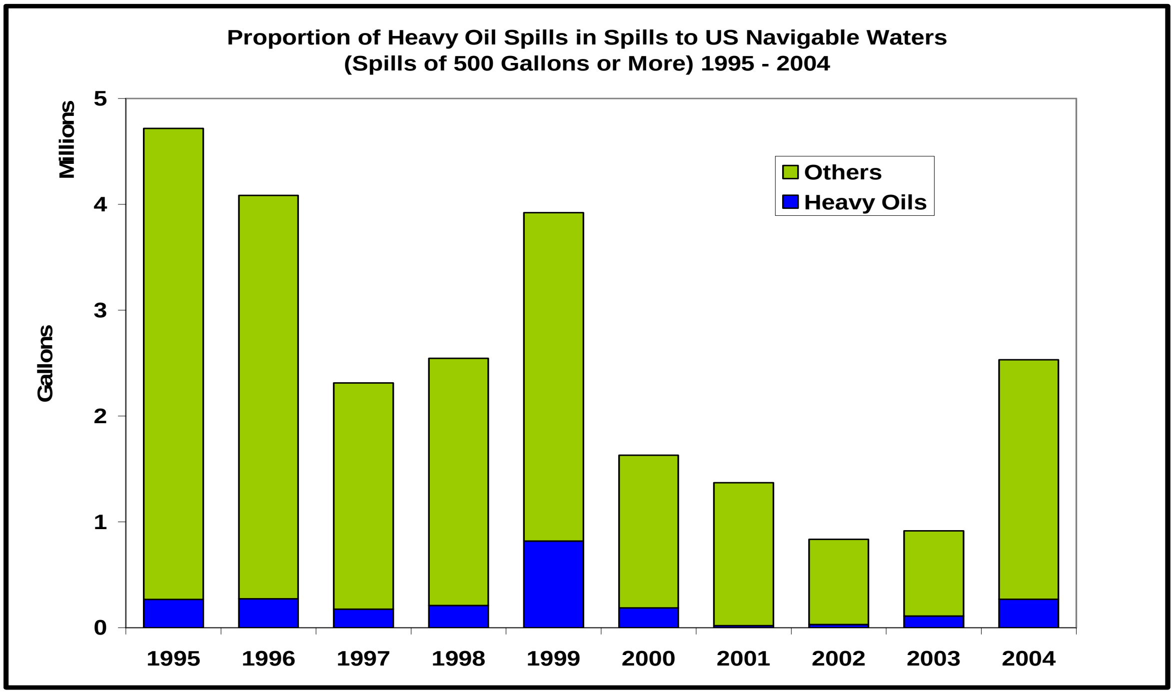

Figure 2. Comparison of heavy oil spills to all oil spills in U.S. navigable waters, 1995-2004.

Table 2. Annual heavy oil spillage in U.S. waters (ERC, 2006).

Year	Volume Spilled (gallons)	Number Spills	Average Spill Volume (gallons)
1995	266,991	23	11,608
1996	272,907	14	19,493
1997	176,117	11	16,011
1998	208,488	15	13,899
1999	817,320[1]	15	54,488
2000	186,926	13	14,379
2001	19,070	9	2,119
2002	29,708	6	4,951
2003	108,814	5	21,763
2004	268,200	4	67,050
Total	**2,354,541**	**115**	**225,761**
Average	**235,454**	**12**	**22,576**
SD	**224,557**	**6**	**21,191**

Notes: 1) Of the 817,320 gallons of heavy oil spilled into U.S. waters in 1999, 688,230 are attributed to a spill at the Marathon Ashland Petroleum oil refinery at Catlettsburg, Kentucky. Of the total spilled, 285,230 gallons entered Chadwick's Creek and Big Sandy River, and the remainder was contained on shore.

3.2 Trends in Spillage Cost

The ERC Basic Oil Spill Cost Estimation Model (BOSCEM) was used to conduct an analysis of estimated costs and damages for all oil spills of at least 500 gallons into U.S. navigable waters during 1995-2004. Spill cost figures generated by the BOSCEM model were used to identify trends versus actual reported spill cost data, as not all spill cost figures are reported, and the data that are reported are often ambiguous due to different accounting procedures used by government agencies and private industry.

The BOSCEM model is described in detail in Etkin (2004). This model *estimates* oil spill response costs, environmental damages, and socioeconomic damages, based on characteristics of each spill (oil type, spill size, location characteristics, spill response methodology, and site sensitivity). The results provide a general picture of the magnitude and types of costs and damages that result from different types of oil spills, versus a precise assessment of the costs for each spill. The algorithms for estimation are based on studies of past spills, as well as on models of hypothetical spills. Based on this methodology, costs and damages for oil spills during the last decade were estimated and adjusted to 2004 dollars (see Table 3).

Annual response costs for spills into U.S. navigable waters amount to an estimated $313M. Environmental damages (roughly analogous to "natural resource damages") amount to $139M annually. Socioeconomic damages are estimated at $475M annually. In the last ten years, over $9B in costs and damages have resulted from oil spills into U.S. navigable waters. A similar analysis was conducted to estimate the costs attributed to spills of heavy oil. These costs are presented in Table 4. Viewed together, the data in Table 3 and Table 4 show that heavy oil spills account for approximately 15 percent of the total cost of oil spills in the U.S. ($145M per year for heavy oil versus $927M per year for all oils).

Table 3. Estimated costs of oil spills of 500 gallons or more into U.S. navigable waters 1995-2004 (based on ERC BOSCEM model).

Year	Response Costs (M)	Socioeconomic Damages (M)	Environmental Damages (M)	Total Costs (M)
1995	$698	$889	$276	$1,863
1996	$420	$711	$203	$1,334
1997	$331	$505	$139	$975
1998	$341	$522	$159	$1,022
1999	$462	$600	$168	$1,230
2000	$226	$355	$96	$678
2001	$181	$329	$92	$602
2002	$129	$203	$69	$401
2003	$136	$188	$51	$374
2004	$204	$448	$137	$789
Total	**$3,128**	**$4,750**	**$1,390**	$9,268
Average	**$313 M/year**	**$475 M/year**	**$139 M/year**	**$927 M/year**

Table 4. Estimated costs for heavy oil spills of 500 gallons or more into U.S. navigable waters 1995-2004 (based on ERC BOSCEM).

Year	Response Costs (M)	Socioeconomic Damages (M)	Environmental Damages (M)	Total Costs (M)
1995	$97	$146	$23	$266
1996	$63	$55	$10	$128
1997	$64	$104	$15	$183
1998	$76	$88	$14	$178
1999	$153	$91	$19	$263
2000	$68	$76	$12	$156
2001	$7	$11	$2	$20
2002	$11	$18	$3	$32
2003	$39	$63	$6	$108
2004	$42	$57	$13	$112
Total	**$620**	**$709**	**$117**	**$1,446**
Average	**$62 M/year**	**$71 M/year**	**$12 M/year**	**$145 M/year**

3.3 LF Opportunity Assessment

Reviewing the data in Sections 3.1 and 3.2 provides insight into the relative impact and significance of heavy oil spills in the context of the overall oil spill problem. On the positive side, it is clear that the number of heavy oil spills is declining; this is consistent with the decline in the number of oil spills in general. Only 115 heavy oil spills greater than 500 gallons occurred in the period 1995-2004, for an average of approximately 12 per year. Although the volume of all spills is declining, the volume of heavy oil spills fluctuates significantly from year to year, depending on occurrence of a major heavy oil spill in any given year. Accordingly, heavy oil spill impacts in terms of costs, damages, and increased public attention are episodic in nature.

Heavy oil spills account for roughly 15 percent of the total costs associated with oil spills in general. Within the specific cost categories, heavy oil spills account for 20 percent of the overall response costs, 15 percent of the overall socioeconomic costs, and 8 percent of the overall environmental costs associated with oil spills. Accordingly, the overall cost incurred from heavy oil spills is significant, at approximately $145M per year. Of these costs, the 20 percent contribution of heavy oil to response costs is significant to the USCG as these costs are often covered in part by USCG operating budgets or the Oil Spill Liability Trust Fund.

Although heavy oil spill costs comprise only a moderate percentage of the annual cost attributed to all spills, the cost savings on any particular spill can be significant. As a rule, heavy oil is much more difficult to remove from the environment, such that heavy oil cleanup costs are generally significantly higher than for other types of oil. For comparable spill scenarios (similar oil volume, similar location, similar response scenario), heavy oil will cost from three to six times as much to clean up as a light fuel such as diesel. Based on statistical data (ERC, 2006) a spill of 1,000 gallons of heavy oil could cost approximately $385 per gallon to clean up, whereas a spill of the same volume of lighter oil could cost approximately $82 per gallon. In addition, heavy oil can be very persistent in the environment, particularly if the spill impacts shorelines and salt marshes requiring extensive long-term cleanup operations.

Because of the high cost of removal and persistence of heavy oil, the total response costs associated with heavy oil can be considerable. For instance, cleanup costs for the T/B BOUCHARD No. 120 spill in Buzzards Bay on April 27, 2003, which involved No. 6 oil and extensive shoreline oiling, totaled $36M. Even more recently, cleanup costs for the T/V ATHOS I spill, investigated as part of this study, totaled $175M. Improving the timeliness and effectiveness of a response effort to reduce these costs by even 10 percent would produce a significant cost savings in a particular event.

4. SCENARIO-BASED BENEFIT ANALYSIS FOR USE OF THE LF FOR SPILL RESPONSE

The first approach used to determine the tradeoffs associated with providing an LF capability to the USCG involved performing a scenario-based benefit analysis. In this analysis, the project team closely examined several past heavy oil spills in which responders had difficulty locating and tracking the oil, in order to determine the operational advantages and cost savings that might have been realized had an LF capability been available at the time. The movement and behavior of the spill, and the resulting countermeasures and cleanup actions of responders, were analyzed

to estimate how the information available from the LF data might have altered the effectiveness of the response. The improved response effectiveness would ideally result in reduced cleanup costs, NRD costs, and socioeconomic costs.

4.1 Methodology for Scenario-Based Benefit Analysis

On the basis of historical data alone, it would be difficult to obtain quantitative estimates of the cost savings to be gained by inserting a technology asset into a past spill. Although the general circumstances and outcomes of a spill response effort are routinely recorded, it is often difficult to determine how much oil was spilled, and how much oil was recovered. In addition, it is often difficult to assign a specific portion of the total cleanup costs to individual cleanup actions that might have been facilitated by availability of the technology asset.

Fortunately, this difficulty can be overcome by means of oil spill simulation models that allow spill events to be recreated and then altered at will. For instance, inputs can be changed to reflect the availability of a technology asset. The user of the model can then make quantitative comparisons of the amount of oil recovered offshore, the amount of oil dispersed, the amount of oil impacting the shoreline, and the natural resources impacted with and without the technology asset in place. From these data, the potential savings in cleanup, NRD, and socioeconomic costs can be estimated.

The project team used the Spill Impact Model Analysis Package (SIMAP) model developed by Applied Science Associates (ASA) of Narragansett, RI, to re-create and analyze the heavy oil spills in question. The SIMAP model can produce detailed predictions of the three-dimensional trajectory, fate, impacts, and biological effects of spilled oil. The model originated from the oil fates and biological effects sub-models in the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME).

ASA developed this model in the early 1990s for the U.S. Department of the Interior for use in Natural Resource Damage Assessment (NRDA) regulations under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). SIMAP, an updated version of the NRDAM/CME, allows use of detailed site and event-specific data; simulation of response activities; and a more detailed evaluation of the outputs.

SIMAP has been validated using hindcasts of over 20 spills (French-McCay, 2003, 2004; French-McCay and Rowe, 2004). A detailed description of the SIMAP model is provided in Appendix A of a report titled *Heavy Oil Cost-Benefit Analysis* (PMG, 2006a). The oil spill processes simulated by SIMAP include:

Oil Transport and Fate in the Environment

- Spreading, transport, and entrainment of the oil
- Emulsification (formation of mousse)
- Evaporation and volatilization of volatile components of the oil
- Transport and dispersion of entrained oil in the water column
- Dissolution of soluble (and therefore toxic) components from the oil
- Adsorption of entrained oil and dissolved aromatics to suspended sediments
- Oil sedimentation and re-suspension

- Natural oil degradation
- Shoreline stranding and natural cleansing by erosion

Impact of Oil Countermeasures

- Oil containment and deflection by booms
- Oil dispersion using dispersants
- Oil removal using mechanical recovery and in-situ burning

Impacts of the Spill on Natural Resources

- Impacts on pelagic fish and plankton
- Impacts on demersal fish and benthic invertebrates
- Impacts on wildlife (birds, sea turtles, and marine mammals)
- Impacts to wetlands and other shoreline habitats

Figure 3 provides a schematic diagram showing the various components of the SIMAP model and their interrelationships. An important feature of the SIMAP model that makes it valuable in evaluating technology assets is its ability to determine the mass balance for a spill and to predict the amount of oil that will be dissolved in the water column, sink to the bottom, or impact the shoreline at any point, as a result of countermeasures and cleanup initiatives undertaken at any time and place during the spill. This allows for an analysis of the final disposition of oil resulting from the enhanced oil removal provided by a technology asset (for example, greater removal effectiveness, and expanded time window for countermeasure application).

Increased removal effectiveness reduces the cost of shoreline cleanup, and the cost of NRD and socioeconomic losses. Reductions in cleanup costs and socioeconomic costs were calculated using oil spill cost models (Etkin, 2004 and 2005a) developed by ERC on the basis of historical cost data and statistical algorithms. These costs were calculated using shoreline cleanup data and impact data (for varying shoreline type, oil thickness, and degree of coverage), as determined by SIMAP, as well as costs for on water oil removal operations and for other response-related activities and operations. NRD costs were estimated using methods employed by federal and state trustees under the Oil Pollution Act of 1990 (OPA 90); that is, by determining the scale and cost of habitat restoration that would provide ecological services equal to those lost following the methods in French-McCay and Rowe (2004).

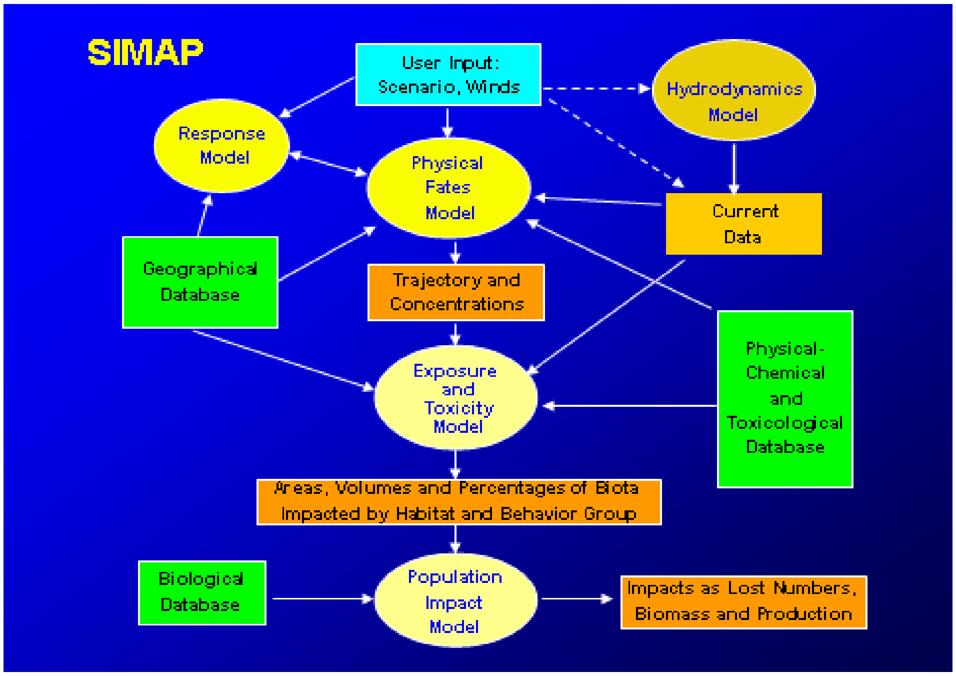

Figure 3. Interrelationship of SIMAP components.

A key factor in determining the effect of response actions on the overall mass balance of a spill is the removal effectiveness of various countermeasures. The approach taken in this study, as in other studies conducted by ASA and ERC, is to relate the specified removal rate as closely as possible to the achievable removal rate. Field studies, case histories, and theoretical studies have shown that actual removal efficiency is considerably less than the "nameplate" efficiency described by manufacturers for specific pieces of skimming equipment. Nameplate efficiency has been "derated" in U.S. Coast Guard regulations to provide Effective Daily Recovery Capacity (EDRC), which is generally 20 percent of nameplate efficiency (based on estimated encounter rates with oil on the water surface).

EDRC provides a more realistic estimate of equipment oil removal capability. However, even these rates are rarely realized in actual spill response operations. This is because of logistical problems, crew changes, oil storage, and decanting problems, and because of the increasingly lower encounter rate due to the spreading of oil slicks over water surfaces, all of which reduce the oil removal capability with each hour that passes after a spill. The anticipated decrease in the mechanical recovery capability over time as a percentage of EDRC, as applied in the scenario-based modeling effort, is shown in Figure 4.

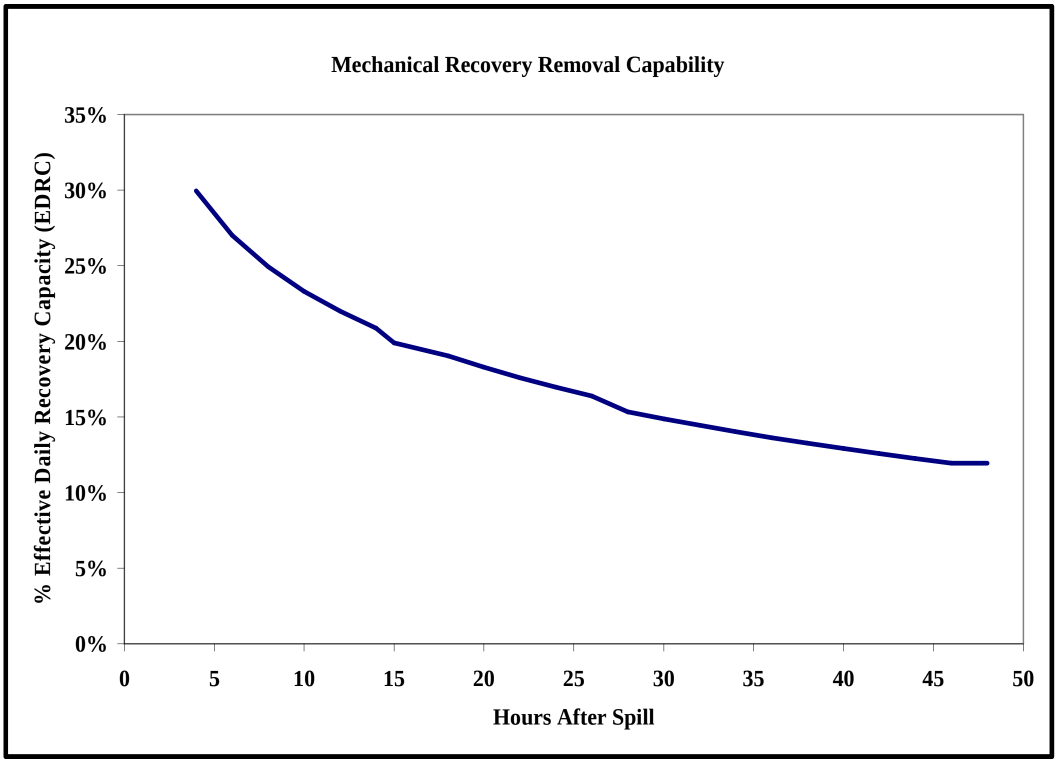

Figure 4. Mechanical recovery capability over time as percentage of EDRC.

In this study, for modeling alternate responses (with and without the use of the LF), the project team made additional assumptions on oil removal rates achievable using LF to facilitate locating and mapping spilled oil. For each spill location, four basic spill-response scenarios involving application of the LF technology were modeled:

No fluorosensor (NF): models the actual response or theoretical response without the benefit of LF, including cessation of oil-removal operations during darkness.

F2 (or F12): models the actual response enhanced by the use of LF at 2 or 12 hours. For the 2-hour scenarios (F2), the oil detection is enhanced by LF at two hours, but oil response operations are still limited by the time required to deliver oil removal equipment to scene (6-12 hours, depending on the location and applicable response regulations/ guidelines). Oil recovery is enhanced during daylight hours once the LF equipment is available on-scene, and the oil-removal equipment is also on-scene. Nighttime removal operations are possible once the LF and the removal equipment are both on-scene, albeit at a rate much reduced from daylight operations.

F24: models the actual response enhanced by the use of LF at 24 hours. Oil recovery is enhanced during daylight hours after 24 hours. Nighttime removal operations are possible after 24 hours, albeit at a rate much reduced from daylight operations.

F72: models the actual response enhanced by the use of LF at 72 hours. Oil recovery is enhanced during daylight hours after 72 hours. Nighttime removal operations are possible after 72 hours, albeit at a rate much reduced from daylight operations.

For each of the three LF scenarios, the project team made assumptions regarding the increased removal rate resulting from the use of LF. The theoretical increase in oil removal rates depends on how much more effective oil removal operations might have been had an LF-based oil

detection capability been available. An additional complicating factor is that oil removal rates are limited by equipment availability, and by efficient deployment and use of this equipment (skimmers; oil recovery vessels; and shoreline-based vacuum trucks).

Theoretically, given a more efficient use of oil removal equipment, a higher baseline oil removal rate might be assumed. Because there are no previous studies, or empirical evidence, upon which to base the assumption of increased removal rates, it was necessary to make some initial estimates on the basis of anecdotal evidence on the degree to which oil location is the limiting factor in on-water recovery operations. A range of oil removal rates was assumed in this study. An additional complicating factor is estimating oil recovery effectiveness for night operations (between sunset and sunrise) because this study assumes that LF usage will lead to night operations. However, even though the oil might be located with the aid of LF and IR sensors at night, the ability to recover the oil depends on the ability to safely maneuver the recovery vessel; illuminate the oil in the vicinity of the vessel; operate the recovery equipment; and provide needed rest for the crew. Because of this, the removal percentages proposed for night operations are conservative (0 percent to 20 percent of daytime recovery percentages). Until the feasibility of night operations is demonstrated, these estimates of improved response effectiveness at night should be regarded as "best case" predictions.

The baseline recovery rates without LF are listed below (A through D). The oil-removal rates with and without LF, for the four basic response scenarios, are summarized in Table 5.

- **A**: 5 percent increase over actual oil recovery during day; 10 percent of day recovery at night.
- **B**: 10 percent increase over actual oil recovery during day; 10 percent of day recovery at night.
- **C**: 20 percent increase over actual oil recovery during day; 10 percent of day recovery at night.
- **D**: 40 percent increase over actual oil recovery during day; 20 percent of day recovery at night.

Table 5. Oil removal rates relative to actual removal in "no fluorosensor" and "with fluorosensor" scenarios.

Scenario	Time of Day	Percent Removed (Hours After Spill)					
		12 hours	24 hours	36 hours	48 hours	60 hours	72 hours
NF	**Day**	100	100	100	100	100	100
NF	**Night**	0	0	0	0	0	0
F12A	**Day**	105	105	105	105	105	105
F12A	**Night**	10	10	10	10	10	10
F12B	**Day**	110	110	110	110	110	110
F12B	**Night**	10	10	10	10	10	10
F12C	**Day**	120	120	120	120	120	120
F12C	**Night**	10	10	10	10	10	10
F12D	**Day**	140	140	140	140	140	140
F12D	**Night**	20	20	20	20	20	20
F24A	**Day**	100	105	105	105	105	105
F24A	**Night**	0	10	10	10	10	10
F24B	**Day**	100	110	110	110	110	110
F24B	**Night**	0	10	10	10	10	10
F24C	**Day**	100	120	120	120	120	120
F24C	**Night**	0	10	10	10	10	10
F24D	**Day**	100	140	140	140	140	140
F24D	**Night**	0	20	20	20	20	20
F72A	**Day**	100	100	100	100	100	105
F72A	**Night**	0	0	0	0	0	10
F72B	**Day**	100	100	100	100	100	110
F72B	**Night**	0	0	0	0	0	10
F72C	**Day**	100	100	100	100	100	120
F72C	**Night**	0	0	0	0	0	10
F72D	**Day**	100	100	100	100	100	140
F72D	**Night**	0	0	0	0	0	20

4.2 Selection of Candidate Spills for the Scenario-Based Benefit Analysis

With the ASA SIMAP model and the ERC cost models readily available, the project team addressed the selection of specific past spills for the scenario-based model simulation and analysis. As part of an oil spill opportunity analysis conducted for this study, a number of candidate spills were identified that involved heavy oil, and that might be relevant for application of LF. These spills are briefly described in Appendix A. In selecting the spills, the project team used several criteria as follows.

- Spill involved a significant quantity of heavy oil.
- Circumstances of the spill indicated that locating and tracking the spill were a problem because of environmental conditions; submerged or sinking oil; nighttime occurrence of the spill; and/or location of the spill in a marsh area.
- Spill involved countermeasures and cleanup efforts.
- Spill involved shoreline impact and cleanup, with associated cleanup costs, and natural resource and socioeconomic damage costs.
- Events during the spill were reasonably well documented to allow reconstruction of spill sequence.
- Cleanup, NRD, and socioeconomic costs were documented.
- Environmental input data were available to allow initialization of the SIMAP model.

Based on these criteria, four spills were selected from the list of 15 in Appendix A. These are listed in Table 6.

Table 6. Heavy oil spills initially selected for scenario-based cost-benefit analysis.

Incident	Date	Location	Oil Spilled
T/B BOUCHARD 155	8/10/1993	Tampa Bay and offshore	330,000 gal. No. 6 fuel
T/V COMMAND	9/27/1998	Offshore Half Moon Bay, CA	3,000 gal. No. 6 fuel
PEPCO Pipeline	4/7/2000	Patuxent River, MD	138,600 gal. No. 6/No. 2 fuels
T/V ATHOS I	11/26/2004	Delaware River	265,000 gal. heavy crude oil

The details of each of these four spills are described in the next section. Ultimately, the T/V ATHOS I spill was not included in the cost-benefit analysis because a closer investigation of the circumstances revealed that LF technology would not have altered the results of the oil recovery efforts (described in Section 4.3.4 and PMG, 2006a). This spill was replaced by a hypothetical spill in the Strait of Juan de Fuca. This hypothetical scenario involved a spill of 1,005,000 gallons (25,000 barrels (bbl)) of No. 6 bunker fuel near Dungeness Spit in the Strait of Juan de Fuca, Washington: a quasi-"worst-case discharge" scenario of concern to the Washington State Department of Ecology (WDOE). The spill also incorporated many of the key attributes and issues identified as being particularly relevant to the LF sensor and heavy oil spills in the analysis of the actual spills.

4.3 Scenarios Considered

Each spill in Table 6 was investigated in detail, and the following information was compiled.

- Spill summary and timeline.
- Response effectiveness and cost.
- Attributes that suggest LF technology might be applicable.
- Key decisions in the response effort that LF surveillance might influence.
- Inputs received from responders on various issues.

The complete information for each of the above topics for each spill is described in detail in the R&DC report detailing the scenario-based analysis (PMG, 2006a). In addition, detailed oil spill trajectory maps showing spill movement and shoreline impact are included. The information

contained in each of these topic areas was used to develop the input parameters and assumptions that were used in the scenario-based modeling effort.

The summaries in this section provide a general overview of each spill, with composite trajectory maps showing the entire area impacted by the spill throughout the course of the spill's movement. These input parameters and assumptions are also summarized for each spill.

4.3.1 Tampa Bay Spill (T/B BOUCHARD 155)

Incident Date	10 August 1993
Spill Sources	T/B BOUCHARD No. 155 and T/B MARITRANS OCEAN 255
Spill Cause	Three-way collision between T/B BOUCHARD No. 155, Philippine freighter BALSA 37, and T/B MARITRANS OCEAN 255 during an attempted passing maneuver
Location	South of Mullet Key, Lower Tampa Bay, Tampa, Florida
Oil Type(s) Spilled	No. 6 fuel oil/Jet A fuel, diesel, and gasoline
Amount Spilled	330,000 gallons of No. 6; 32,000 gallons of lighter fuels (7857 bbl/761 bbl)

Summary: On August 10, 1993, the T/B BOUCHARD No. 155 collided with the Philippine freighter BALSA 37, and the T/B MARITRANS OCEAN 255, during an attempted passing maneuver at the entrance to Tampa Bay (see Figure 5), between Egmont Key and Mullet Key. The T/B MARITRANS OCEAN 255 caught fire and burned for 18 hours. The BALSA 37, which suffered extensive damage in the collision, was intentionally grounded outside the shipping channel, to prevent it from capsizing, and to open the channel for traffic while repairs and stability evaluations were conducted. One cargo tank of the T/B BOUCHARD 155 was penetrated and its contents of 330,000 gallons of No. 6 fuel oil spilled into Tampa Bay.

During the period August 10 through August 12, the spilled oil moved westward out of Tampa Bay under the influence of an easterly wind, as shown in Figure 6. During this time, an offshore oil recovery effort was undertaken, and an estimated 84,000 gallons of oil and water were recovered. From August 13 through 15, the winds became predominantly westerly, and began to drive the oil ashore from St. Petersburg Beach to Madeira Beach. Overflights reported nine miles of heavily oiled beach, and four miles of moderately oiled beach, with the width of oiled beach ranging from three to six meters. Oil also began entering Boca Ciega Bay through John's Pass and, to a lesser extent, Blind Pass. Offshore skimming operations were discontinued, because most of the unrecovered floating oil had come ashore. Ultimately, it was reported that 100,086 gallons of the spilled oil had been recovered offshore.

Between August 15 and 20, an extensive cleanup effort was conducted on the beaches north and south of John's Pass, and in Boca Ciega Bay in the vicinity of John's Pass. Beach cleanup consisted largely of mechanical removal of oiled sediments. Between August 21 and 31, cleanup of the beaches from southern St. Petersburg Beach to Madeira Beach continued. By August 23, it was reported that 97,482 gallons of oil had been removed from the beaches.

On August 30 and 31, State of Florida divers conducted a small survey to look for additional tar balls and tar mats off Treasure Island. The divers discovered three large patches of submerged

oil about 20 feet by 150 feet, two inches thick, adhering to the bottom. The tar mats were located offshore in 6 to 20 feet of water. The dive team estimated that these submerged mats contained 5,040 gallons of oil (which amounts to 1.5 percent of the spilled oil).

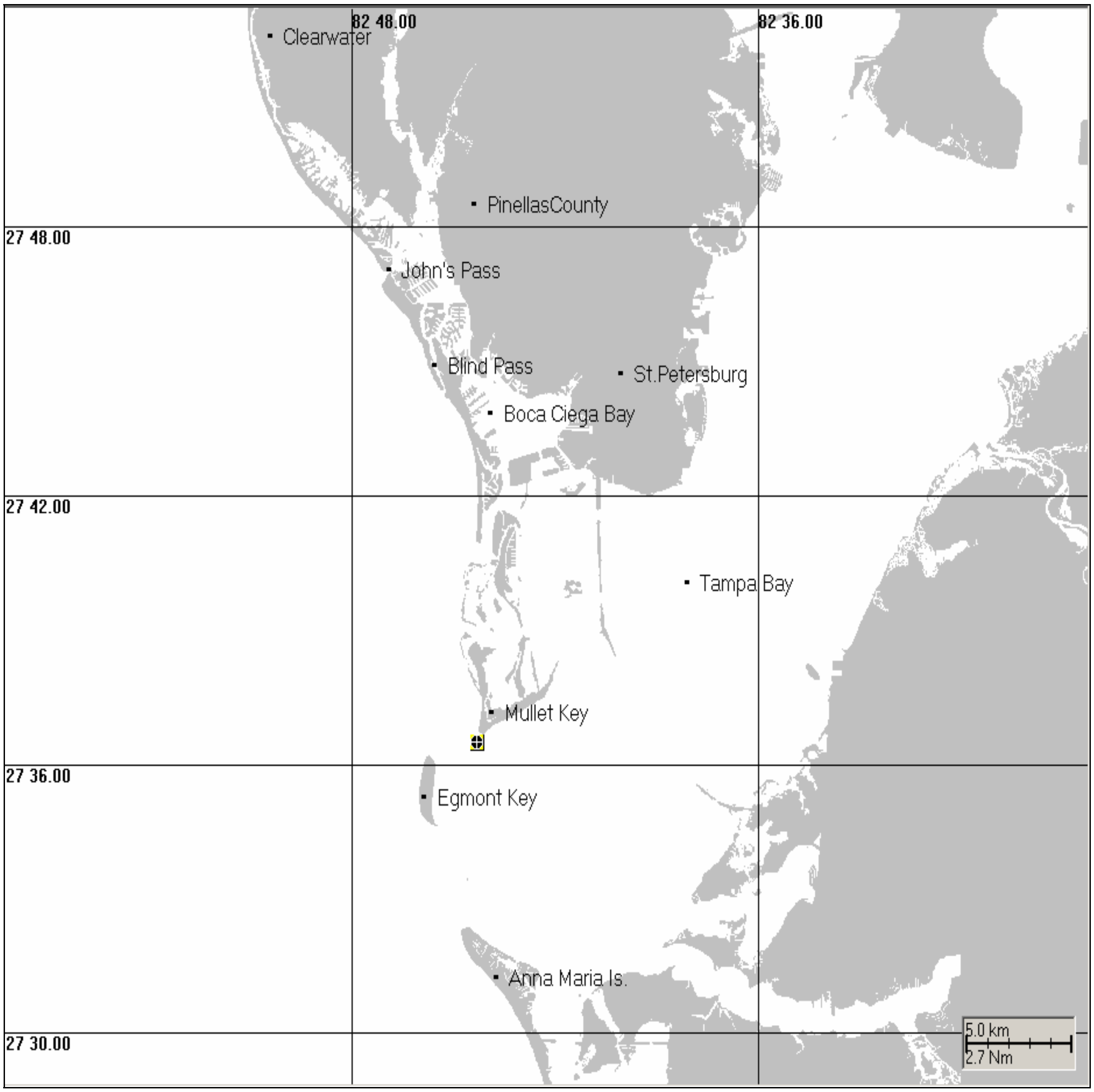

Figure 5. General area impacted by the Tampa Bay spill.

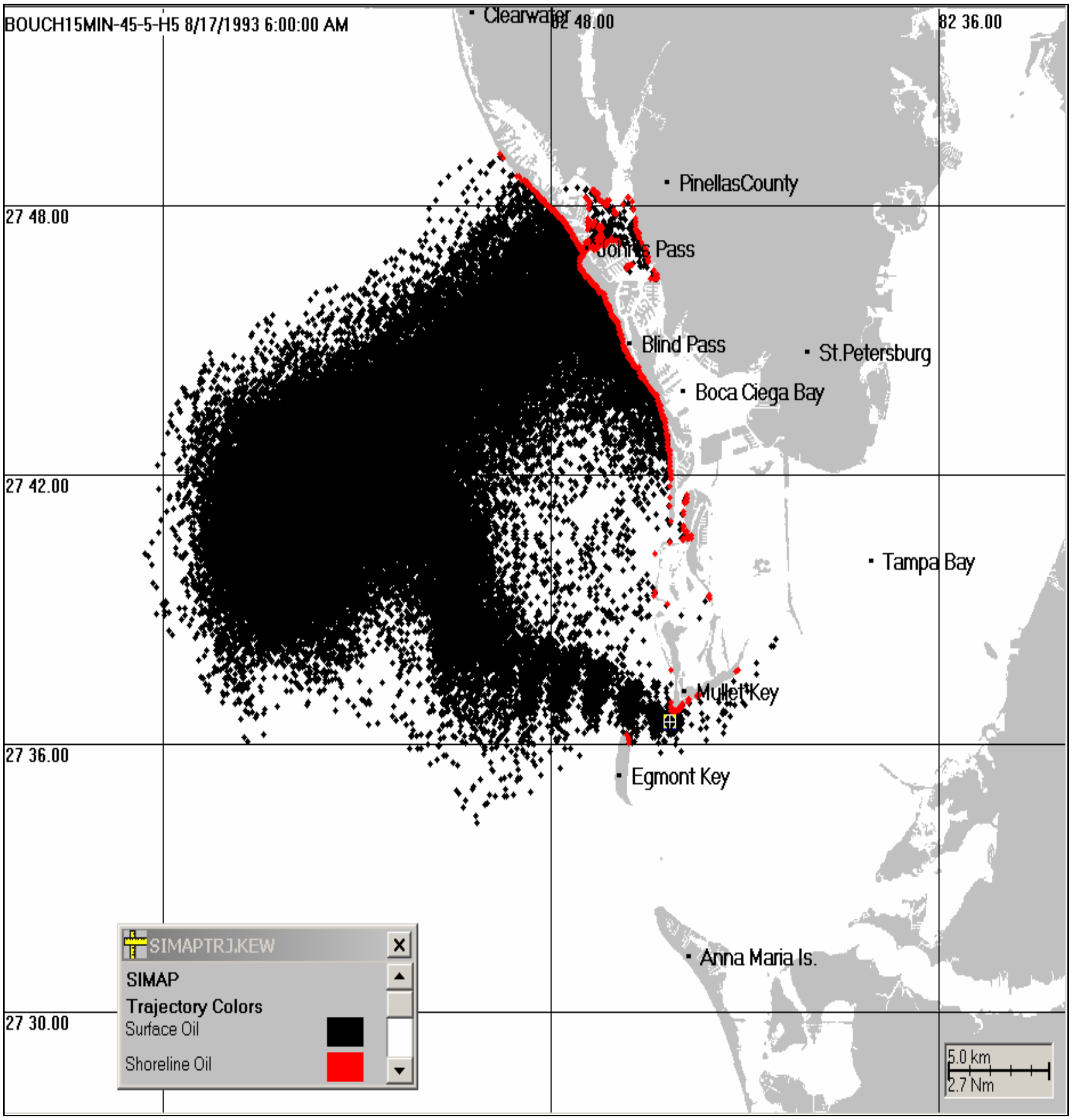

Figure 6. Composite SIMAP spill trajectory plot for the T/B BOUCHARD 155 spill.

By September 1, the shoreline cleanup was essentially complete, with the exception of the submerged oil in the surf-zone off Treasure Beach. Oil recovery operations to remove the submerged oil continued for several additional days, with divers removing the oil manually. However, in the subsequent months (and even years), there was clear evidence that additional submerged oil remained offshore in John's Pass, as beaches would be re-oiled following storms, heavy surf, or dredging operations offshore.

Reported response costs were $1,700,000 ($2,260,000 in 2006 dollars) in USCG costs; $66,498,000 ($88,442,340 in 2006 dollars) in responsible party (RP) costs; and $400,000 ($532,000 in 2006 dollars) in other Federal costs, for a total of $68,598,000 ($91,235,340 in 2006 dollars) (Etkin, 1998). Third party damages were reported to be $30,303,000 ($40,302,990 in 2006 dollars). NRDA costs were settled at $1,804,000 ($2,400,000 in 2006 dollars) (Etkin, 1998).

The Tampa Bay spill response involved issues of tracking oil offshore and tracking submerged oil in several sensitive areas. The potential opportunities for the use of the laser fluorosensor in the T/B BOUCHARD 155 spill response included:

- Tracking oil offshore during daylight to enhance mechanical recovery efforts;
- Tracking oil during darkness to continue mechanical recovery efforts;
- Tracking oil movement toward shore during darkness to allow for better strategic preventive booming and other near-shore countermeasures;
- Tracking and detecting submerged oil to enhance recovery and reduce later re-oiling of beaches.

In reviewing the spill events, the project team identified three decision points where the presence of an LF capability might have made a difference. The initial key decisions were the deployment of the offshore skimmers (including their location and skimming pattern), and the decision on conducting night operations. It is possible that the surveillance data from the LF equipment might have improved the daytime skimming operations (higher oil encounter rate) and allowed night operations as well. This would have increased the offshore oil recovery effectiveness.

The second point where an LF capability might have played a role was in alerting responders to the onshore movement of oil on August 14 through 15. The movement of oil from its offshore location eastward toward the beaches at Clearview, St. Petersburg, and Treasure Island, during night hours, was reported to have caught some responders by surprise. Having LF available to track oil at night might have allowed some advance preparation, including preventive exclusionary booming at John’s Pass or at other locations.

Finally, there is the possibility that an LF capability might have allowed detection and mapping of submerged oil in the near-shore areas off Treasure Island, as well as inside John’s Pass near Eleanor Island. Submerged oil in these areas was ultimately mapped by divers with the cleanup operation taking several weeks, and it is clear that not all of the oil was located and removed, resulting in periodic re-oiling of the beaches.

Inputs and Assumptions to the SIMAP Model: After considering all of the issues and information analyzed above, the project team decided that the primary benefit of having LF technology on-scene would have been enhancement of the offshore recovery operations before the oil came ashore. Accordingly, the oil removal effectiveness was adjusted in the SIMAP model to account for this enhancement. Alternative spill responses modeled for this spill are shown in Table 7. A “no response” (NR) scenario was included as a baseline for all response scenarios. This baseline is where the oil would have gone with no response of any kind. It demonstrates the relative effectiveness of all response scenarios in reducing shoreline and other impacts.

Table 7. Assumptions on increased effectiveness of oil recovery for the T/B BOUCHARD 155 spill.

Scenario	Fluorosensor	Day Oil Recovery	Night Oil Recovery
NR	none	none	none
NF	none	normal	none
F12A	12 hours	105% normal > 12 hours	10% > 12 hours
F12B		110% normal > 12 hours	
F12C		120% normal > 12 hours	
F12D		140% normal > 12 hours	20% >12 hours
F24A	24 hours	105% normal > 24 hours	10% > 24 hours
F24B		110% normal > 24 hours	
F24C		120% normal > 24 hours	
F24D		140% normal > 24 hours	20% > 24 hours
F72A	72 hours	105% normal > 72 hours	10% > 72 hours
F72B		110% normal > 72 hours	
F72C		120% normal > 72 hours	
F72D		140% normal > 72 hours	20% > 72 hours

Oil removal capability was based on information from Etkin (1998) on oil response equipment reported to have been on-scene: 3 Marco Class XI C skimmers; 3 rope mop skimmers; 2 weir disk skimmers; and 24 portable vacuum transfer units with skimmer heads.

4.3.2 T/V COMMAND SPILL

Incident Date	27 September 1998
Spill Source	T/V COMMAND
Spill Cause	Illegal bunker discharge
Location	Off San Francisco, California
Oil Type(s) Spilled	No. 6 fuel oil (IFO 380)
Amount Spilled	Reported as 2,500-51,450 gallons (3,000 gallons most likely)

Summary: On September 26, 1998, the tanker T/V COMMAND departed San Francisco harbor after experiencing a leak from one of its fuel tanks while in port. The tank was emptied and the leak was temporarily repaired. Once the tanker was underway, the master ordered the crew to transfer fuel from the holding tank back into the temporarily repaired fuel tank. During the transfer procedure, a hose coupling failed, resulting in oil being pumped onto the deck and into the Pacific Ocean, in the shipping channel off Half Moon Bay (see Figure 7).

Reports of spill amounts varied from 3,000 gallons to more than ten times this amount (as much as 51,450 gallons). The 3,000 gallon amount was incorporated into the model for this spill, because this volume matched the amount of spilled oil specified in the natural resource damage assessment and in legal settlements. The damage from this amount of oil also correlated well with observed impacts, especially the impacts to birds and the shoreline.

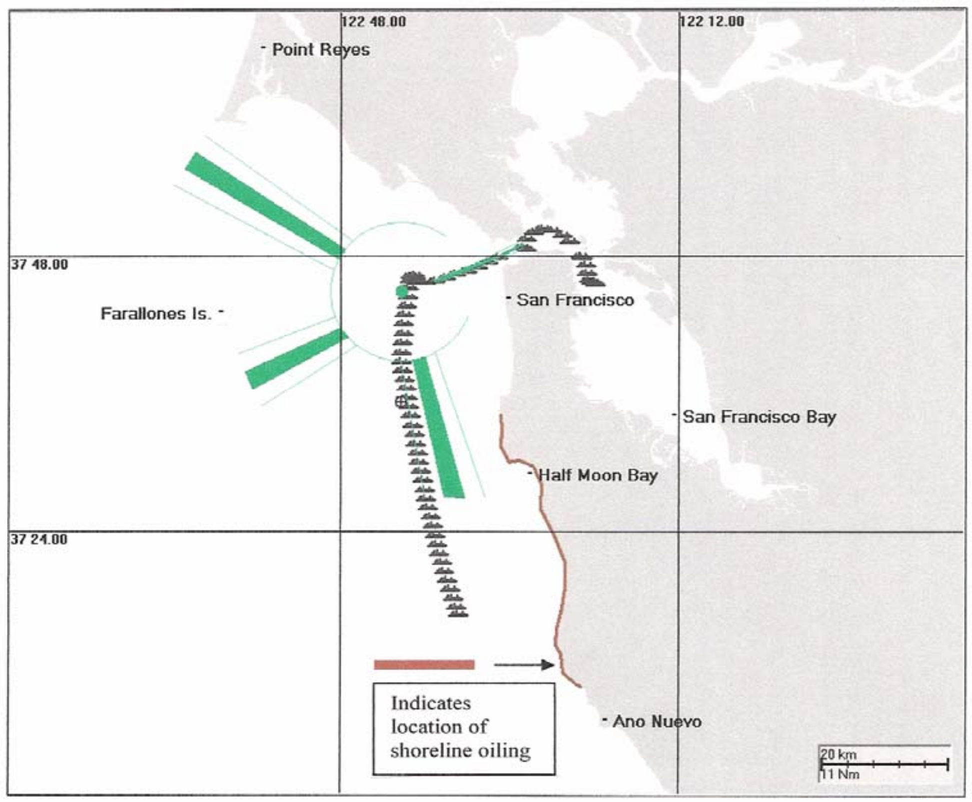

Figure 7. T/V COMMAND track and general area impacted by the spill.

On the morning of September 27 (within eight hours of the spill), an oil slick was observed by a routine civilian over flight in the Southern Traffic Lane, just south of the entrance to San Francisco Bay. The slick was subsequently observed by a small fishing boat and by a USCG helicopter on the afternoon of September 27 (Plourde and Henderson, 2001).

By the morning of September 28, the amount and extent of the spill became clear, and a full response effort was mounted under the Incident Command System (ICS). An oil spill response vessel (OSRV) was deployed offshore and shoreline protection and cleanup preparations were launched.

The movement of the spill is described in French and Isaji, 1999. The oil moved very little in the first few days, because of light winds and currents, which kept the spill in the vicinity of the southbound traffic lane (see Figure 8). Beginning on September 30, oil began to wash ashore, largely in the form of scattered tar balls, along 15 miles of beaches, mainly in San Mateo County. The main biological impact consisted of bird fatalities (with 1,500 common murres killed), and bird oilings, including the oiling of six brown pelicans (an endangered species).

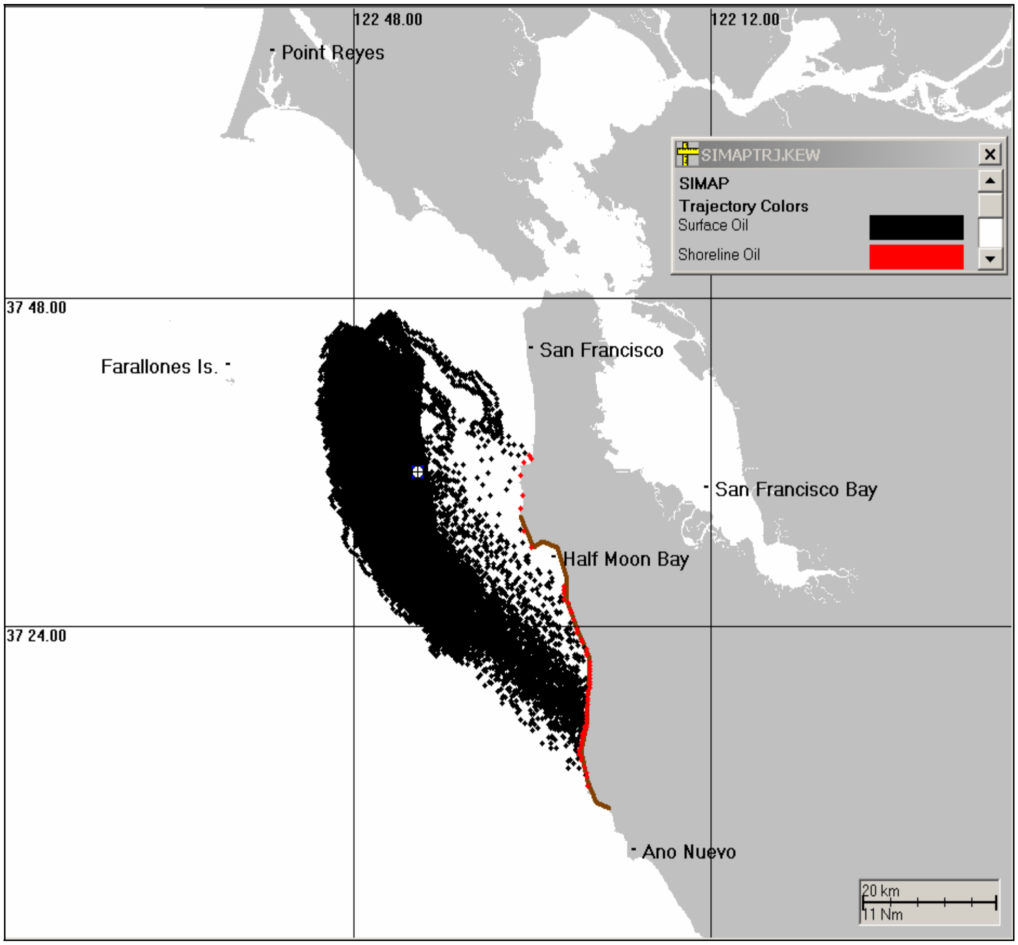

Figure 8. Composite SIMAP spill trajectory plot for the T/V COMMAND spill.

Oil skimmers were deployed and were able to recover approximately 600 gallons of oil and water by the end of September 30. Shoreline cleanup personnel recovered 9,200 pounds of tar balls and oiled debris from the 15 miles of impacted beaches near Half Moon Bay, San Gregorio Beach, and Pescadero State Beach.

Total cleanup costs were reported to be $3.6M ($4,248,000 in 2006 dollars). The NRD settlement was $5.5M ($6,490,000 in 2006 dollars). Civil claims totaled $1,604,984 ($1,797,582 in 2006 dollars). Human use impacts (beaches) were settled at $113,386 ($126,992 in 2006 dollars), according to Plourde and Henderson (2001).

The potential opportunities for the use of the LF in the T/V COMMAND spill response included:

- More immediate determination of the size and actual extent of the spill;
- Tracking the oil offshore after the spill to enhance mechanical recovery efforts;
- Tracking oil during darkness to continue mechanical recovery efforts;
- Detecting and tracking tar balls on the water surface (reported as difficult to see from the air).

Further investigation into the capabilities of LF technology indicated that tracking of tar balls on water surface would likely have been difficult and inaccurate, because the LF technology would most likely not have been able to detect isolated patches of scattered tar balls.

The response action that might have been affected by LF availability was earlier initiation of offshore oil-recovery efforts while the slick was intact; that is, the oil had not yet dissipated into tar balls. On September 27, there were several observations of the spill, but the magnitude of the spill was not fully appreciated, and the spill was not reported to USCG Marine Safety Office (MSO) San Francisco until the morning of September 28. If the full extent of the spill had been accurately determined early on September 27, the response might have been accelerated by up to 24 hours, possibly increasing the effectiveness of offshore oil recovery. In addition, the ability to accurately locate and define slick patches as the spill began to break up on September 28 might have further facilitated skimmer deployment and recovery effectiveness.

As the slick broke up and began to come ashore, an LF capability would not likely have been able to play a role. This limited role is due to the fact that the oil came ashore as small patches of tar balls over an extended length of shoreline (15 miles). Detection by the LF on a specific overflight would have been very difficult.

Inputs and Assumptions to the SIMAP Model: After considering all of the issues and information analyzed above, the project team decided that the primary benefit of having an LF capability on-scene would have been enhancement of the offshore recovery operations before the oil came ashore. The start time for the use of the LF was determined to be the point of notification of MSO San Francisco on the morning of September 28, not the beginning of the actual spill, or the earlier spill observations on September 27. Accordingly, the effectiveness of oil recovery was adjusted in the SIMAP model to account for the possible enhancement of the offshore oil recovery operations that did occur. Alternative spill responses modeled for this spill are shown in Table 8.

Table 8. Assumptions on increased effectiveness of oil recovery for the T/V COMMAND spill.

<table>
<tr><th>Scenario</th><th>Fluorosensor</th><th>Day Oil Recovery</th><th>Night Oil Recovery</th></tr>
<tr><td>NR</td><td>none</td><td>none</td><td>none</td></tr>
<tr><td>NF</td><td>none</td><td>normal</td><td>none</td></tr>
<tr><td>F12A</td><td rowspan="4">12 hours</td><td>105% normal > 12 hrs.</td><td rowspan="3">10% > 12 hrs.</td></tr>
<tr><td>F12B</td><td>110% normal > 12 hrs.</td></tr>
<tr><td>F12C</td><td>120% normal > 12 hrs.</td></tr>
<tr><td>F12D</td><td>140% normal > 12 hrs.</td><td>20% >12 hrs.</td></tr>
<tr><td>F24A</td><td rowspan="4">24 hours</td><td>105% normal > 24 hrs.</td><td rowspan="3">10% > 24 hrs.</td></tr>
<tr><td>F24B</td><td>110% normal > 24 hrs.</td></tr>
<tr><td>F24C</td><td>120% normal > 24 hrs.</td></tr>
<tr><td>F24D</td><td>140% normal > 24 hrs.</td><td>20% > 24 hrs.</td></tr>
<tr><td>F72A</td><td rowspan="4">72 hours</td><td>105% normal > 72 hrs.</td><td rowspan="3">10% > 72 hrs.</td></tr>
<tr><td>F72B</td><td>110% normal > 72 hrs.</td></tr>
<tr><td>F72C</td><td>120% normal > 72 hrs.</td></tr>
<tr><td>F72D</td><td>140% normal > 72 hrs.</td><td>20% > 72 hrs.</td></tr>
</table>

4.3.3 PEPCO Pipeline Spill

Incident Date	7 April 2000
Spill Sources	Potomac Energy and Power Company Pipeline
Spill Cause	Pipeline break
Location	Chalk Point, Maryland
Oil Type(s) Spilled	No. 2 and No. 6 fuel oils
Amount Spilled	138,600 gallons

Summary: At 9:30 AM on April 7, 2000, a pipeline break at the PEPCO Power Plant at Chalk Point, MD, released 138,600 gallons of a mixture of No. 2 and No. 6 fuel oils into an adjacent marsh, over the course of five hours. The loss of oil was detected in the pipeline, but the spill site could not be located until 6:00 PM, eight and a half hours after the spill occurred. Containment and exclusion booms were then deployed in Swanson Creek.

For the first 24 hours, a strong southeast wind held the oil in the salt marsh at the spill site. In the late afternoon of April 8, the winds became strong from the northwest, blowing the oil out into the Swanson Creek (see Figure 9). Winds remained strong from the northwest and west for the next two days, entraining the oil into the water, and moving it downstream. On April 9, the booms were breached and the oil spread into the Patuxent River. Responders “chased” oil in the river but failed to contain it.

On April 10, the oil spread past the Benedict Bridge in the nighttime hours. Failure to boom sensitive downstream creeks as directed by the Federal On-Scene Coordinator (FOSC) allowed the oil to enter Trent Hall and Indian Creeks on April 11. Over the next two weeks, the oil continued to move downstream in the Patuxent River, contaminating a substantial length of shoreline, as indicated in Figure 10.

The response to the PEPCO pipeline spill was complicated by significant strategic errors, miscommunications, and failures to follow the orders of the FOSC. (Much of this is detailed in EPA, 2000, as well as in Pollution Reports (POLREPs); in Incident Action Plans; and in personal interviews with Federal On-Scene Coordinators Stanton and Jarvela.) Minimal efforts were made to respond to the spill in accordance with the facility response plan. Booms were installed in improperly anchored and twisted configurations, using poorly maintained, disintegrating booms. When the FOSC appeared on-scene the following day, 24 hours after the spill occurred, she found a spill that was over 69 times the volume reported (2000 gallons), and involving not No. 2 fuel but a mixture of No. 6 and No. 2 fuel oils. PEPCO did not carry out FOSC directives for response measures to keep oil within the marsh and creek adjacent to the spill site, to prevent the oil from entering the Patuxent River, and to prepare for a predicted storm. Oil was transported by wind and current out of the marsh and creek and spread for miles downstream. Very little oil was recovered, despite the presence of oil removal equipment on-scene. Extensive oiling of wetlands resulted in a very complex and expensive cleanup response.

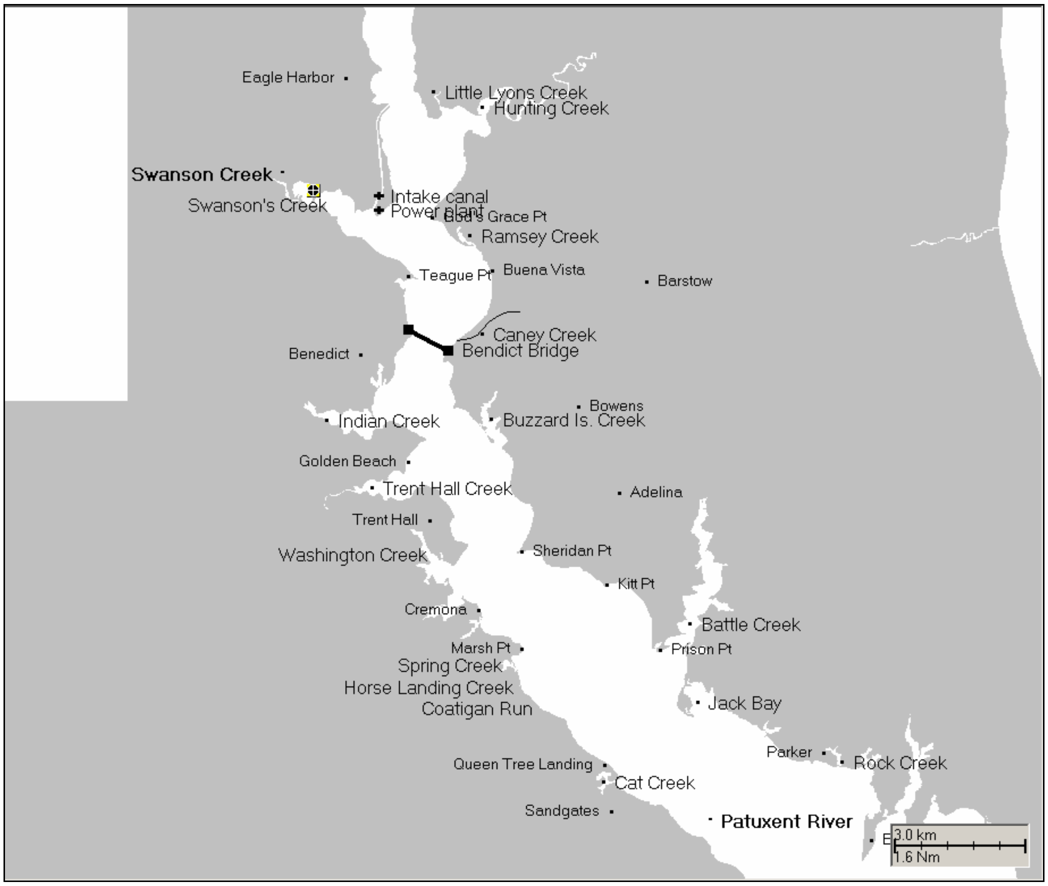

Figure 9. Vicinity of the PEPCO pipeline spill.

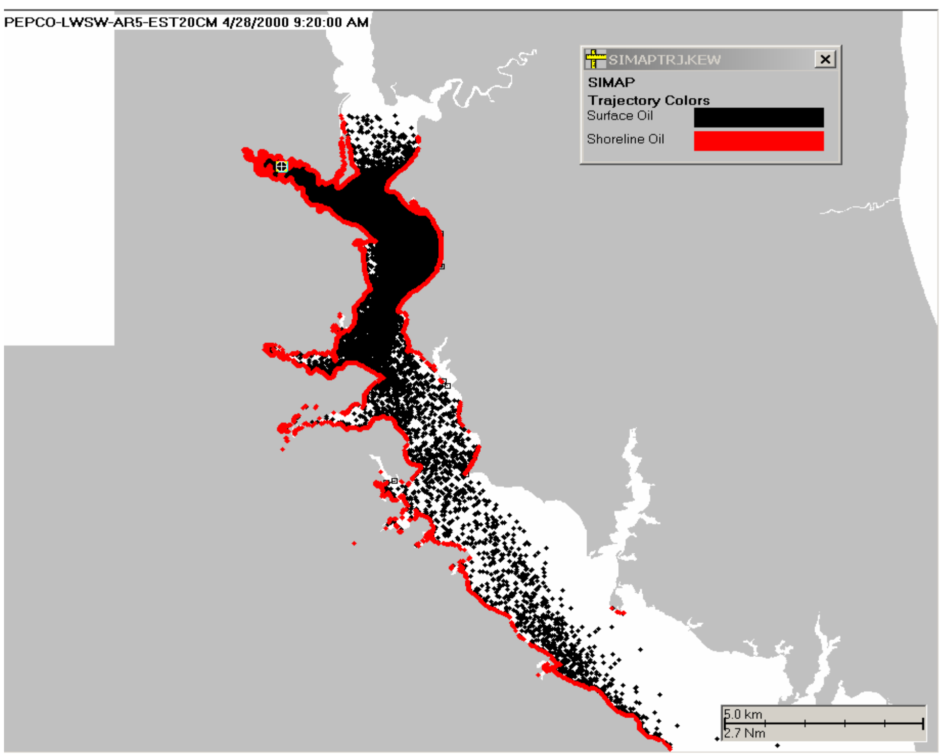

Figure 10. Composite SIMAP spill trajectory plot for the PEPCO spill.

Oil spill response costs for the PEPCO pipeline spill were reported by PEPCO to be as high as $82M ($91.8M in 2006 dollars). ERC analyzed the spill costs and estimated that actual legitimate spill-response costs were $56M ($62.7M in 2006 dollars), which might have been $46M ($51.5M in 2006 dollars) if negotiated rates were in place and other irregularities were removed. Had PEPCO response personnel followed FOSC orders, the response costs would likely have been $19M to $23M ($21.3M to $25.8M in 2006 dollars) as determined by Etkin, French-McCay, and Rowe (2006); and Etkin and French-McCay (2006). NRD costs were settled at $2,710,498 in 2002 dollars ($2,900,233 in 2006 dollars) (NOAA, 2002).

Potential opportunities for enhancing the response through use of LF in the PEPCO pipeline spill response were:

- Locating the oil spill in the marsh after an oil loss was initially detected in the pipeline, but no oil spill could be located with visual inspection of the marsh;
- Tracking oil during darkness to continue mechanical recovery efforts;
- Tracking oil during daylight to enhance mechanical recovery operations.

By far, the most significant issues with respect to employing LF technology in the PEPCO spill were locating the spill more quickly, and gaining a better appreciation of the extent of the spill. Improvements in these areas would potentially have resulted in more effective containment and recovery actions on the part of the responsible party, and have prevented movement of oil into Swanson Creek, and subsequently the Patuxent River, on the evening of April 8.

In addition, the use of LF technology once the oil had moved out of Swanson Creek would have allowed better detection, tracking, and on-water recovery as the oil moved downstream in the Patuxent River. It is possible that LF would have allowed continuation of on-water recovery at night.

Tracking the oil at night after it had moved downstream into the Patuxent River after the storm was also a key problem. Spill responders unsuccessfully attempted to recover oil during nighttime hours. Oil spill responders were also reported to have been “chasing oil” across the wide Patuxent River in a haphazard fashion. Being able to better locate the oil during the day and at night would have allowed a better rate of oil recovery from these locations.

Inputs and Assumptions to the SIMAP Model: It is likely that the use of LF technology would have increased the timeliness and efficiency of oil containment and recovery operations, resulting in an overall increase in the percentage of oil recovered. Alternative spill responses modeled for this spill are shown in Table 9. These responses assume an over flight would have taken place at two hours after notification, and that recovery operations would have been initiated at 12 hours.

Table 9. Assumptions on increased effectiveness of oil recovery for the PEPCO pipeline spill.

Scenario	Fluorosensor	Day Oil Recovery	Night Oil Recovery
NR	none	none	none
NF	none	normal	none
F2A	2 hours	105% normal > 12 hours	10% > 12 hours
F2B		110% normal > 12 hours	
F2C		120% normal > 12 hours	
F2D		140% normal > 12 hours	20% > 12 hours
F24A	24 hours	105% normal > 24 hours	10% > 24 hours
F24B		110% normal > 24 hours	
F24C		120% normal > 24 hours	
F24D		140% normal > 24 hours	20% > 24 hours
F72A	72 hours	105% normal > 72 hours	10% > 72 hours
F72B		110% normal > 72 hours	
F72C		120% normal > 72 hours	
F72D		140% normal > 72 hours	20% > 72 hours

The spill was originally reported to the National Response Center as being a spill of 2,000 gallons of No. 2 fuel, although more than this amount of oil was thought to be "missing" from the pipeline. A spill of this relatively small magnitude might not have warranted an over flight under most circumstances. However, even before reporting the spill, PEPCO, the responsible party, had conducted several over flights looking for the leak location, and was unable to find the 138,600 gallons of a mixture of No. 2 and No. 6 fuels that had spilled into the marsh. It is reasonable to assume that the responsible party would request the USCG to use LF in an over flight when it was clear oil had spilled somewhere on land, or in the marsh along a specific length of pipeline, even though the exact location was not known.

4.3.4 T/V ATHOS I Spill in the Delaware River

Incident Date	26 November 2004
Spill Sources	T/V ATHOS I
Spill Cause	Structural break in hull after hitting submerged object
Location	Paulsboro, New Jersey
Oil Type(s) Spilled	Heavy (Bachaquero Venezuelan) crude oil
Amount Spilled	265,000 gallons (6310 bbl)

Summary: On November 26, 2004, the T/V ATHOS I, a 750-foot single-hull oil tanker, flying the Cypriot flag, struck a submerged 15-foot piece of centrifugal pump casing while being towed to the dock of the CITGO Asphalt Refinery in Paulsboro, NJ. The CITGO Refinery is located on the Delaware River, downstream from Philadelphia, PA.

The T/V ATHOS I was carrying approximately 13 million gallons of Bachaquero Venezuelan crude oil, a heavy crude oil that is heated during transport. The initial report indicated that

30,000 gallons were released; however, as the response effort progressed, this estimate was increased to 265,000 gallons. The final spill estimate of 265,000 gallons made this spill the second largest spill in the history of the Delaware River.

Although the oil floated, there was concern that some of the oil would mix with sediment and sink. Soon after the spill, pooled oil was reported on the river bottom at the collision site, and shoreline assessment teams reported that oil stranded on sandy inter-tidal areas failed to re-float with the rising tide. A significant amount of the oil remained on the bottom. Between November 26 and December 10, the oil moved up and down the Delaware River, ultimately spreading downstream of Wilmington, DE, and beyond (see Figure 11). Most of the mobile submerged oil was located about one meter off the bottom, although small amounts of oil were detected on snares suspended in the middle and upper layers of the water column.

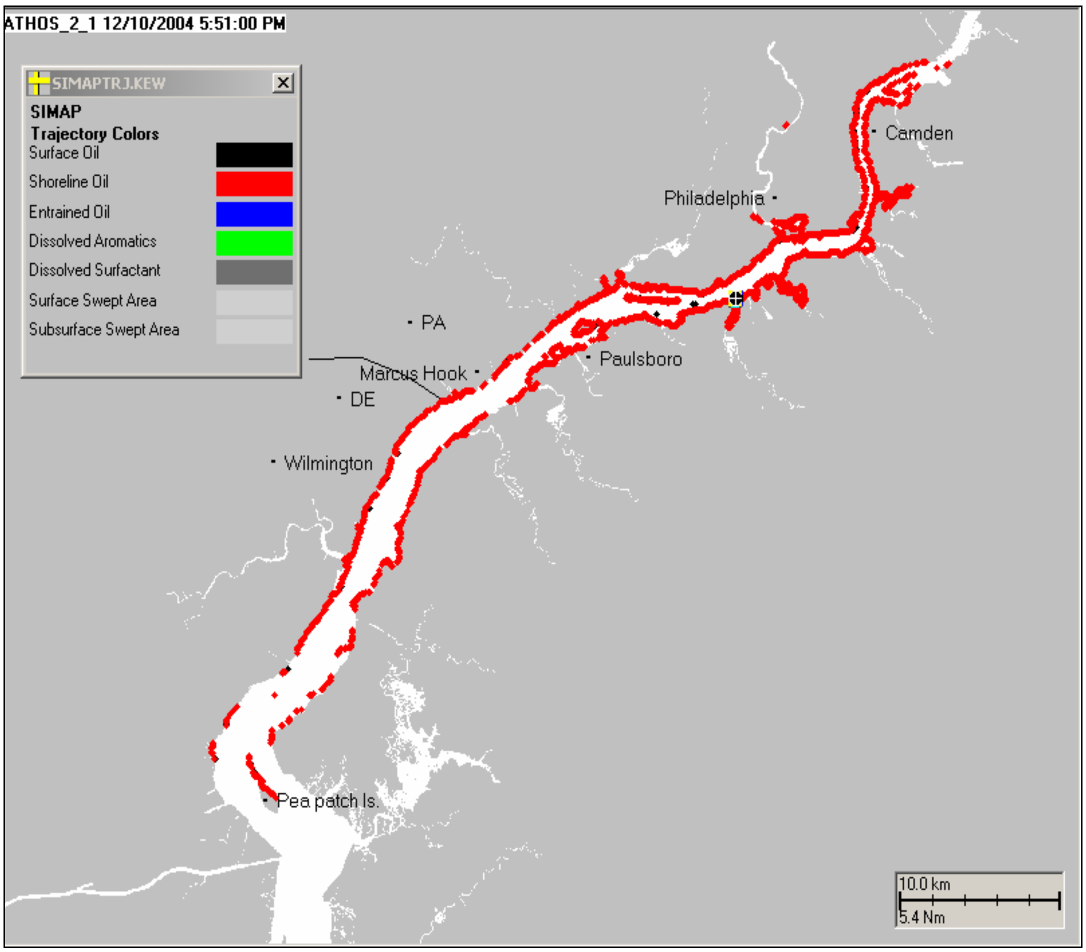

Figure 11. Composite SIMAP spill-trajectory plot for the ATHOS I spill.

Countermeasures and cleanup for the T/V ATHOS spill focused primarily on recovering submerged oil. Two types of submerged oil were involved, according to initial assessments – pooled oil near the initial spill site, and mobile submerged oil as the spill moved downstream. Sorbent oil snares attached to chains towed behind survey vessels were used to detect and track mobile submerged oil. However, this method was time-consuming and failed to provide a comprehensive picture of where the oil was located.

Spill impacts included oiled birds and infrastructure contamination along the shoreline. Of the oiled birds located, 389 were rehabilitated and released, 186 did not survive. In addition, 57 miles of shoreline were oiled, from the Tacony-Palmyra Bridge to south of the Smyrna River in Delaware, contaminating 247 recreational boats, and causing the closure of industrial water intakes.

According to USCG data, 221,910 gallons of oil and oily liquid, and 18,178 gallons of submerged oil, were recovered. Another 17,761 tons of oily solids (cleanup materials and oil) were collected. Spill response costs reported in the media were as high as $175M (of which $42M was paid through the Oil Spill Liability Trust Fund); however, it is unclear what costs were included in this figure.

Accurately locating the mobile suspended or submerged oil could have been a key factor in assisting with oil recovery. Innovative techniques to locate the oil in the water column, including fixed and towed oil-snare samplers, were employed, but these techniques were time consuming and did not provide the strategic surveillance desired. Use of LF technology might have made this process unnecessary, or at least more effective. In addition, knowing exactly where the oil was migrating might have prevented the closure of industrial water intakes along the Delaware River, resulting in decreased economic damage.

However, a closer examination of various reports on the spill, and contacts with spill response personnel, indicated that LF probably would not have made a substantial difference in overall spill surveillance. The oil was released at a depth of ten meters, resulting in half the oil submerging and coming to rest on the bottom sediments, under the tanker, at this depth. According to the NOAA Scientific Support Coordinator (SSC) (Personal communication, Ed Levine, NOAA SSC), the submerged oil that was not trapped in the trenches on the bottom at the spill site probably moved along the river at all depths, with a large amount traveling near the bottom. Because the river is in excess of 30-feet deep (ten meters) in many places, it is unlikely that LF (with depth penetration of only one to two meters) would have detected the oil. Also, it is unlikely that the submerged oil would have left a sheen on the surface that LF technology could detect. This conclusion was also supported by USCG response personnel involved in the spill. (Personal communication with CDR Vicky Huyck (2005), USCG Sector Delaware Bay, and CDR Roger Laferriere (2006), USCG Atlantic Strike Team.)

Thus, it is unlikely that LF technology would have helped in this aspect of the spill response. On-water recovery was not hampered by the inability to see the floating oil on the water surface. Because the spill was confined to the upper reaches of the river in populated and accessible areas, surface-oil movement and shoreline oiling were readily observed from the shore and from the air.

In view of these factors, the T/V ATHOS I spill was dropped from consideration for scenario-based cost-benefit modeling. To replace it, the project team proposed developing a hypothetical scenario that incorporated many of the issues identified in the four historical spills examined.

4.3.5 Hypothetical Spill in Strait of Juan de Fuca, Washington

Incident Date	N/A, Hypothetical
Spill Sources	Bunker Fuel Barge
Spill Cause	Unspecified
Location:	Strait of Juan de Fuca, Washington
Oil Type(s) Spilled	Bunker C
Amount Spilled	1,050,000 gallons (25,000 bbl)

Summary: For the final scenario, the project team selected a hypothetical spill scenario for a Bunker C spill in the Strait of Juan de Fuca. Development of the hypothetical spill scenario for the Strait of Juan de Fuca is outlined in detail in PMG (2006a). The scenario was originally developed as part of a previous study for the Washington State Department of Ecology (WDOE) (French-McCay, et. al., 2005a, 2005b, and 2005c). In this previous study, oil spill fate and effects modeling and analysis were performed to evaluate the implications of spill response planning standards being considered by WDOE in their rulemaking related to oil spill preparedness (WA State Contingency Plan Rule).

The scenario involves a 1,050,000-gallon spill of Bunker C (heavy fuel) in the Strait of Juan de Fuca along the shipping lanes. The volume of the spill was based on worst-case discharges of bunker fuel carried by barges in Washington State coastal waters. The spill model simulation resulted in 60 percent of the oil coming ashore, assuming no response.

Figure 12 shows the composite trajectory and shoreline impacted for this hypothetical spill. As for the implications of having an LF capability, LF technology could be used to track heavy oil that might submerge in near-shore areas by coming into contact with sediment. In addition, the spill scenario involves the release of oil at night, when oil cannot easily be detected visually.

As for implications of having an LF capability to support the response effort, officials at WDOE, and other spill response personnel in the state, have indicated that accurately locating the oil, particularly in the high currents and winds in the Strait of Juan de Fuca, and during periods of darkness, would be a key factor in responding to the spill. Better spill tracking and mapping toward being able to direct on-water response resources strategically could be a distinct advantage in facilitating offshore oil recovery during both daylight and nighttime operations.

Inputs and Assumptions to the SIMAP Model: The primary benefit of having the LF on-scene would be an enhancement of the offshore recovery operations before the oil came ashore. Alternative spill responses modeled for this spill are shown in Table 10.

Modeled capabilities for mechanical containment and recovery for each of the scenarios were based on the location and type-specific response capability standards or guidelines developed by WDOE (Etkin, 2005b). In the model simulation, protective booms were located at sensitive areas, as indicated in the State of Washington Geographic Response Plans (GRPs), according to the schedule of booming in the appropriate standards. It was assumed that enough boom was available to make the modeled boom placements at the times required, and also that the placements were performed according to the plan. The mechanical recovery modeling involved simulating only the capacities of WDOE’s response planning standards.

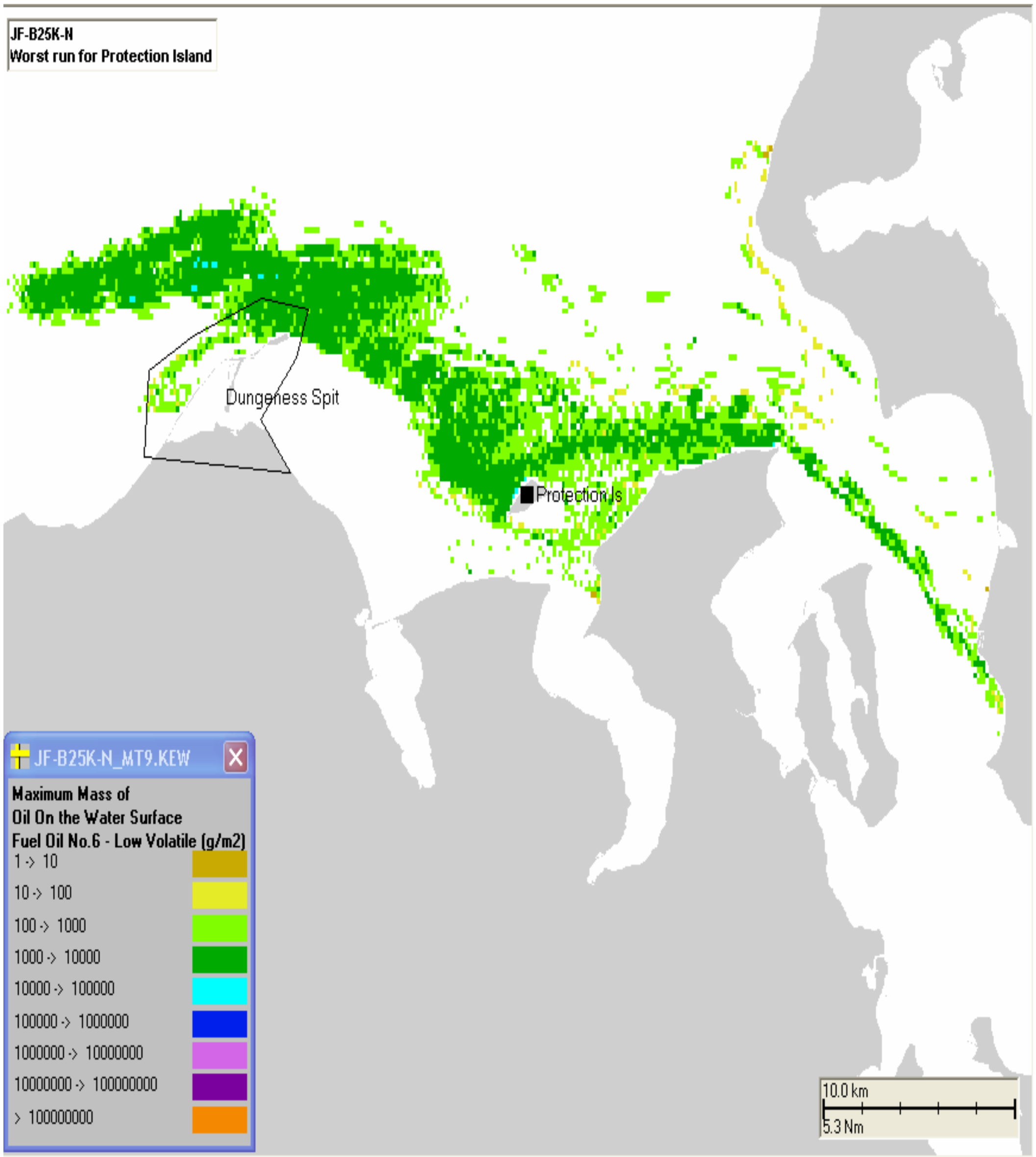

Figure 12. Composite SIMAP trajectory plot for the Strait of Juan de Fuca–Bunker C spill.

Table 10. Assumptions on increased effectiveness of oil recovery for the Strait of Juan de Fuca spill.

Scenario	Fluorosensor	Day Oil Recovery	Night Oil Recovery
NR	none	none	none
NF	none	normal	none
F2A	2 hours	105% normal > 6 hours	10% > 6 hours
F2B		110% normal > 6 hours	
F2C		120% normal > 6 hours	
F2D		140% normal > 6 hours	20% >6 hours
F24A	24 hours	105% normal > 24 hours	10% > 24 hours
F24B		110% normal > 24 hours	
F24C		120% normal > 24 hours	
F24D		140% normal > 24 hours	20% > 24 hours
F72A	72 hours	105% normal > 72 hours	10% > 72 hours
F72B		110% normal > 72 hours	
F72C		120% normal > 72 hours	
F72D		140% normal > 72 hours	20% > 72 hours

4.4 Results of the Scenario-Based Benefit Analysis

Using the SIMAP model in accordance with the methodology outlined in Section 4.1 allows predicting the enhanced effectiveness of oil spill-response efforts. The increase in response effectiveness depends on whether LF is brought into service at 2 hours, 12 hours, 24 hours, and 72 hours after a spill occurs. It also depends on the selected enhanced removal efficiency, ranging from 5 percent to 40 percent over the actual recovery rate during daylight hours, and 10 percent to 20 percent over the predicted day recovery rate at night. The recovery parameters and their abbreviations are repeated below for convenience:

No fluorosensor (NF): the actual response or theoretical response is conducted without the benefit of LF, including cessation of oil removal operations during darkness.

F2 (or F12): the actual response is enhanced by the use of LF at 2 or 12 hours. Oil recovery is enhanced during daylight hours after 2 or 12 hours. Nighttime removal operations are possible once the LF and removal equipment are both on-scene, albeit at a rate much reduced from daylight operations.

F24: the actual response enhanced by the use of LF at 24 hours. Oil recovery is enhanced during daylight hours after 24 hours. Nighttime removal operations are possible after 24 hours, albeit at a rate much reduced from daylight operations.

F72: the actual response enhanced by use of LF at 72 hours. Oil recovery is enhanced during daylight hours after 72 hours. Nighttime removal operations are possible after 72 hours, albeit at a rate much reduced from daylight operations.

Enhanced removal effectiveness options are:

A: 5 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

B: 10 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

C: 20 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

D: 40 percent increase over actual oil recovery during day; 20 percent of day recovery at night.

For this matrix of assumptions, a number of parameters were calculated that reflect the enhanced response effectiveness. These parameters include the following:

- Oil removal rates under different responses;
- The percentage of oil coming ashore, and the number of gallons recovered;
- Mass balance (maximum amount in each environmental compartment over time); and,
- Spill costs with and without LF.

The environmental compartments considered for the mass balance include oil evaporated, oil in the water column, oil in sediments, oil on the shoreline, oil degraded naturally, and oil removed. The oil removal rates assigned to each simulation model run drive the mass balance (oil remaining) at any time after the spill, as well as the amount of oil recovered, and the amount coming ashore. These predictions are then used to determine the projected costs incurred with and without the LF capability in place. The results of the model runs for the first three parameters are presented in tables and graphs in Appendix B. The results for the parameter of greatest interest (the costs incurred with and without the LF capability) are presented in this section for the modeling of three actual spills (the T/B BOUCHERD 155, the M/V COMMAND, and the PEPCO spills), as well as for the modeling of the hypothetical spill in the Strait of Juan de Fuca. A discussion of the uncertainties involved in the cost calculations is provided on page B-12 of Appendix B.

4.4.1 Costs With and Without LF for the T/B BOUCHARD 155 Spill in Tampa Bay

Cost estimates for response, natural resource damage (NRD) and for known socioeconomic damages for the T/B BOUCHARD spill, under the NF and various LF response scenarios, are shown in Table 11. The NRD costs were based on the legal settlement (summarized in Section 4.3.1), which included negotiated restoration project costs and government (but not responsible party) assessment costs. For this spill case, most of the NRD costs were related to recreational-beach use loss, which is proportional to shoreline oiling. Thus, for the alternative response scenarios, the proportionate change in NRD cost from the NF case was calculated on the basis of the percent change in volume of oil that came ashore.

Table 11. Spill costs with and without LF for the T/B BOUCHARD 155 spill.

Scenario	Costs ($ million)[1]		Socioeconomic[2]	% Difference from NF[3]		Socioeconomic
	Response[4]	NRD		Response	NRD	
NF	$91.2	$2.4	$40.3M in damage to impacted beach-front properties, tourist beaches, recreational fishing, and marinas.	0.0	0.0	Beach damages reduced with increased removal. Keeping oil out of Boca Ciega Bay would reduce marina impacts. Potential $4 M savings.
F12A	$89.8	$2.3		-1.5	-3.0	
F12B	$88.8	$2.3		-2.6	-5.2	
F12C	$87.3	$2.2		-4.3	-8.6	
F12D	$80.5	$1.8		-11.7	-23.4	
F24A	$89.4	$2.3		-2.0	-4.0	
F24B	$88.7	$2.3		-2.8	-5.5	
F24C	$87.0	$2.2		-4.6	-9.3	
F24D	$83.3	$2.0		-8.7	-17.4	
F72A	$90.1	$2.3		-1.3	-2.5	
F72B	$90.2	$2.3		-1.2	-2.3	
F72C	$88.6	$2.3		-2.9	-5.8	
F72D	$87.1	$2.2		-4.5	-9.0	

Table Notes:
(1) All costs converted to 2006 dollars.
(2) Because there was very little reliable information available on socioeconomic costs available for the spills modeled for this study, this category of costs is presented in a qualitative rather than a quantitative manner. That is, the way in which changes in oil fate, based on differences in spill response, might affect costs is mentioned only qualitatively.
(3) Negative percent difference indicates a *decrease* in costs from the no fluorosensor (NF) case with the alternate responses.
(4) Response costs were calculated based on actual reported response costs of $68,598,000 ($91,235,340 in 2006 dollars). Adjustments to costs for alternate response scenarios were made based on increased oil removal and reductions in shoreline oiling.

4.4.2 Costs With and Without LF for the T/V COMMAND Spill

Cost estimates for response, NRD, and known socioeconomic damage for the T/V COMMAND spill under the NF and various LF response scenarios are shown in Table 12. The NRD costs were not based on the legal settlement (summarized in Section 4.3.2), which was based on negotiated restoration project costs and government (but not responsible party) assessment costs, because the change in the NRD costs, from change in impact, could not be quantified from the information available. Instead, NRD costs were calculated based on compensatory habitat restoration of a scale that would replace the biological losses (all bird injuries), using methods employed by natural resource trustees under OPA 90 regulations and guidance.

There is very little difference in NRD from using LF in this spill. This result is mainly due to the fact there is relatively little increase in oil removal resulting from the use of LF, because of oil spread prior to the late time at which LF would be deployed (more than 24 hours after the spill occurred). There is virtually no change in shoreline oiling from the use of LF.

Reductions in response costs and NRD would likely have been realized with a more timely use of LF, after first observations of an oil slick. Having a 12- or even 24-hour head start on oil response operations, compared to the delayed start in the actual case, could have aided the removal of more oil offshore, toward reducing shoreline impacts and NRD, mainly to birds.

Table 12. Spill costs with and without LF for the T/V COMMAND spill.

Scenario	**Costs ($ million)[1]**		**Socioeconomic**	**% Difference from NF[2]**		**Socioeconomic**
	Response	**NRD**		**Response**	**NRD**	
NF	$4.25	$9.73	$1.8M in civil damages, based on impacts to beaches.	0.0	0.0	Reductions in damages to beaches by increased on-water oil removal might have saved $90,000 in socioeconomic damages.
F12A	$4.25	$9.72		0.0	-0.1	
F12B	$4.25	$9.72		0.0	-0.1	
F12C	$4.25	$9.77		0.0	0.4	
F12D	$4.25	$9.71		0.0	-0.1	
F24A	$4.25	$9.72		0.0	0.0	
F24B	$4.25	$9.72		0.0	0.0	
F24C	$4.25	$9.72		0.0	-0.1	
F24D	$4.25	$9.75		0.0	0.3	
F72A	$4.25	$9.73		0.0	0.0	
F72B	$4.25	$9.72		0.0	0.0	
F72C	$4.25	$9.72		0.0	0.0	
F72D	$4.25	$9.72		0.0	0.0	

Table Notes:
(1) All costs converted to 2006 dollars.
(2) Negative percent difference indicates a *decrease* in costs with the alternate responses.

4.4.3 Costs With and Without LF for the PEPCO Spill on the Patuxent River

Cost estimates for response, NRD, and known socioeconomic damages for the PEPCO spill under the no laser fluorosensor (NF) and various LF response scenarios are shown in Table 13. The NRD costs were not based on the legal settlement (summarized in Section 4.3.3), which was based on negotiated restoration project costs and government (but not responsible party) assessment costs, because the change in the NRD costs, from change in impact, could not be quantified from the information available. Instead, NRD costs were calculated based on compensatory habitat restoration of a scale that would replace the fish and wildlife losses, using methods employed by natural resource trustees under OPA 90 regulations and guidance. NRD costs for habitat restoration were not included, as these costs would not vary by the alternative response scenarios examined. In the actual case, the habitat restoration was for oiled marshes in Swanson Creek, which would not be changed by use of LF.

Table 13. Spill costs with and without LF for the PEPCO Pipeline spill.

Scenario	Costs ($ million)[1]		Socioeconomic	% Difference from NF[2]		Socioeconomic
	Response[3]	NRDA		Response	NRDA	
NF	$25.8	$0.775	No socioeconomic cost data available. Impacts to recreational boating and beachfront property reported.	0.0	0	Removing oil before it impacted shorelines and spread widely through the river would have reduced damages.
F2A	$24.3	$0.652		-5.9	-16	
F2B	$24.2	$0.645		-6.2	-17	
F2C	$24.4	$0.704		-5.5	-9	
F2D	$24.2	$0.666		-6.2	-14	
F24A	$24.3	$0.681		-5.7	-12	
F24B	$24.5	$0.658		-5.0	-15	
F24C	$24.8	$0.684		-3.9	-12	
F24D	$24.3	$0.668		-5.7	-14	
F72A	$25.5	$0.786		-1.2	1	
F72B	$25.9	$0.748		0.5	-4	
F72C	$26.0	$0.798		0.7	3	
F72D	$25.2	$0.766		-2.2	-1	

Table Notes:
(1) All costs converted to 2006 dollars.
(2) Negative percent difference indicates a *decrease* in costs with the alternate responses.
(3) Oil spill response costs for the PEPCO pipeline spill were reported to be as high as $82M ($91.8M in 2006 dollars) by the responsible party (RP). ERC analyzed the spill costs and estimated that legitimate spill-response costs were $56M ($62.7M in 2006 dollars), which might have been $46M ($51.5M in 2006 dollars) if negotiated rates had been in place and other irregularities had been removed. Had the RP followed FOSC orders, the response costs would likely have been $19M–$23M ($21.3M –$25.8M in 2006 dollars). See Etkin, D.S., D. French-McCay, and J. Rowe, 2006; Etkin, D.S., and D. French-McCay, 2006.

Using LF technology to enhance oil-recovery efforts would have saved about $1M in the cost of the response to the PEPCO pipeline spill, if the LF technology had been used within the first 24 hours. This conclusion assumes a reasonable response cost of $25.8M for the actual response if FOSC orders had been followed, and if reasonably well-maintained equipment (particularly booms) had been installed according to industry standards. Earlier use of LF (in the first 2 to 12 hours) would have led to higher cost savings. Tens of thousands of dollars, up to $100,000 in NRD costs, might have been saved with the effective use of LF during the response.

4.4.4 Costs With and Without LF for the Hypothetical Spill in the Strait of Juan de Fuca

Cost estimates for response, NRD, and socioeconomic costs for the hypothetical spill in the Strait of Juan de Fuca, under the NF and various LF response scenarios, are shown in Table 14.

Response cost savings of $4M could be realized from using LF to enhance on water recovery operations. NRD might be reduced by $200,000 to $900,000. Socioeconomic damage reductions might net another $4M in savings.

Table 14. Spill costs with and without LF for the hypothetical Strait of Juan de Fuca spill.

Scenario	**Costs ($ million)[1]**		**Socioeconomic**	**% Difference from NF[2]**		**Socioeconomic**
	Response[3]	**NRD**		**Response**	**NRD**	
NF	$97.4	$6.6	$87.8M in socioeconomic damages for the NF scenario.	0	0	Reductions in impacts by even 5 percent would mean savings of $4M in socioeconomic damages.
F12A	$97.4	$6.3		0	-4	
F12B	$96.8	$6.4		-1	-2	
F12C	$97.7	$6.3		0	-5	
F12D	$95.5	$5.7		-2	-13	
F24A	$97.6	$6.2		0	-5	
F24B	$96.8	$6.3		-1	-3	
F24C	$96.9	$6.1		-1	-7	
F24D	$93.2	$5.7		-4	-14	
F72A	$98.7	$6.3		1	-4	
F72B	$101.4[4]	$6.2		4	-5	
F72C	$97.4	$6.2		0	-5	
F72D	$95.4	$6.0		-2	-9	

Table Notes:

(1) All costs converted to 2006 dollars.
(2) Negative percent difference indicates a *decrease* in costs with the alternate responses.
(3) Based on: Etkin, et. all., 2005.
(4) This number differs from the others because the model transport includes random variability (due to turbulence), which results in variation in the specific water areas and shoreline locations oiled. This randomization caused variations in the results for F72A and F72B that are greater than any trend that might have been induced by changes in the assumed spill response.

4.5 Applicability and Cost Savings Associated with LF Use

The scenario-based oil spill modeling analysis described in previous sections provides a wealth of numerical data on the level of response, NRD, and socioeconomic cost savings that might have been attained had LF technology been available during a past response effort. These cost savings vary widely, depending on the time at which LF was hypothetically introduced into the spill response effort (2, 12, 24, or 72 hours after the spill), and the estimated increase in oil removal effectiveness assumed.

As indicated in Section 4.1, these quantitative results are subject to various assumptions on the input end, and qualifications on the output end. The primary uncertainty with respect to model input is the increase in percentage of oil removal that can be attributed to the use of LF. As indicated in Table 5, the increased removal effectiveness used in modeling the spills varied from 5 percent to 40 percent, depending on the time at which the LF asset was applied. The percentage was also adjusted for the time elapsed since the LF asset arrived on-scene to contribute to the response effort. In addition, the percentage differed significantly for daytime versus nighttime operations. Accordingly, it is difficult to accurately assign a specific overall cost savings figure for application of LF technology to a particular spill.

However, when considered across a range of increased removal percentages, the data provide at least a range of representative response, NRD, and socioeconomic cost-savings figures for each spill. Table 15 provides an overview of these representative figures, for each of the four spills modeled, by consolidating the data contained in Table 11, Table 12, Table 13, and Table 14. When the data from the four spills are considered together, a number of observations can be made concerning the cost savings that might result from having an LF asset available.

Table 15. Ranges of response, NRD, and socioeconomic cost savings attained by using a laser fluorosensor.

Spill Scenario	Response Time	Potential Cost Savings ($M)		
		Response	NRD	Socioeconomic
T/B BOUCHARD 155 330,000 gallons No. 6 Offshore (1993)	12 hours	1.4-10.7	0.1-0.6	4.0
	24 hours	1.8-7.9	0.1-0.4	
	72 hours	1.0-4.1	0.1-0.2	
T/V COMMAND 3,000 gallons No. 6 (1998)	12 hours	0	0-0.02	0.09
	24 hours	0	0-0.01	
	72 hours	0	0-0.01	
PEPCO pipeline 138,600 gallons No. 6 (2000)	2 hours	1.4-1.6	0.07-0.13	no data available
	24 hours	1.0-1.5	0.09-0.12	
	72 hours	0.75-0.80	0-0.03	
Strait of Juan de Fuca 1,050,000 gallons Bunker C	12 hours	0-1.9	0.02-0.09	4.0
	24 hours	0-4.2	0.4-0.9	
	72 hours	0-2.0	0.3-0.6	

Table 15 indicates that larger spills result in a greater potential cost savings, with savings associated with the T/B BOUCHARD 155, the PEPCO pipeline, and the Strait of Juan de Fuca spills being on the order of $5M to $15M, in 2006 dollars, subject to the time when the LF asset was applied, and to the estimated increase in removal effectiveness. Clearly, the savings associated with the T/V COMMAND spill were negligible, partially due to the smaller amount of oil involved in the spill, but also due to the distance from shore, the rapid breakup of the slick, the fact the spill was not discovered until 12 hours after the illegal discharge, and the fact that the USCG Marine Safety Office was not notified of the spill until 24 hours after the spill.

It is also clear that a significant portion of the cost savings are in spill response costs, particularly for the larger spills involving extensive shoreline cleanup efforts. This point is significant in that these cost savings most directly relate to the USCG by indicating a reduced level of effort by the FOSC and potentially reduced charges to the Oil Spill Liability Trust Fund. It is precisely these cost savings that could justify an expenditure of USCG funds to acquire, operate, and maintain an LF capability. NRD cost savings and socioeconomic cost savings accrue to third parties, and are less likely to justify a direct expenditure of USCG funds for a mission-specific system.

When considered together, the data in Table 15 for the T/B BOUCHARD 155, the PEPCO pipeline, and the Strait of Juan de Fuca spill suggest that each large spill might result in up to $10.7M savings in response costs, up to $0.6M savings in NRD costs, and potentially as much as

$4.0M in socioeconomic costs. This savings suggests a representative cost savings for a large heavy oil spill of $5M to $15M. A conservative estimate on the frequency of occurrence of heavy oil spills of this nature and magnitude is perhaps once every five years. Together, these estimates suggest a potential annual cost savings of $1.0M to $3.0M per year. This annual cost saving range provides an approximate cost savings figure that can be compared to the annual cost of having an LF asset available (including amortized acquisition cost, platform cost, operating cost, training costs and maintenance cost).

The cost savings above include response, environmental and socioeconomic costs. Of these three cost categories, the one of most direct significance to the USCG are response costs as these are most likely to be paid by with USCG operating funds or the Oil Spill Liability Trust Fund, if not paid by the responsible party. The analysis above indicates that response cost savings alone can be as high as $10M for a large heavy oil spill with the LF available at 12 hours, and can be $2.0M to $5.0M with the LF available at 24 to 72 hours. If one such spill occurs every five years, the scenario-based analysis suggests that annual response cost savings could be as high as $2M per year, and more likely to be $0.5M to $1.0M per year.

The scenario-based model analysis also provides some qualitative insight into the type of oil spill for which an LF capability might be directly applicable. Certainly, the larger heavy oil spill is a likely candidate for LF, particularly in the offshore region, where spilled oil must be tracked over a wider area. It is also clear that an LF capability is most needed in the earlier stages of a spill, that is, before the spill breaks up into tar balls. (This suggests that the number of LF units required, and their pre-deployment, would have to meet a 2 to 12 hour response time).

The benefit of early use of LF to improve oil recovery rates will increase the ability to respond more quickly and effectively with mechanical oil containment and recovery equipment. Delays in initiating responses, and inefficiencies in the response efforts, serve to reduce not only oil removal rates but also any potential benefit to be gained from employing better surveillance capabilities.

The T/B BOUCHARD 155 spill and T/V ATHOS I spill show that the presence of submerged oil alone does not necessarily warrant application of an LF capability, particularly if the submerged oil is dispersed and is more than two meters below the surface. In addition, because submerged oil tends to represent a small portion of the oil spilled, and resides in specific areas (often associated with depressions in the bottom topography), it is questionable whether an airborne LF asset would detect it.

5. STATISTICAL BENEFIT ANALYSIS FOR USE OF THE LF FOR SPILL RESPONSE

In addition to the scenario-based cost-savings analysis described in Section 4, performed using the SIMAP model, the project team conducted a second cost-savings analysis, and this one was performed using two statistics-based oil spill cost models developed by ERC. These two models are the Basic Oil Spill Cost Estimation Model (BOSCEM), and the Oil Spill Response Cost-Effectiveness Analytical Tool (OSRCEAT) model. Both models were applied to 115 heavy oil spills that occurred between 1995 and 2004 (these spills are listed in Appendix A).

5.1 Methodology for Statistics-based Cost-Savings Analysis

ERC created BOSCEM by way of performing extensive analyses on oil spill response, socioeconomic, and environmental damage cost data taken from historical oil spill case studies, as well as from oil spill trajectory and impact analyses. The methodology and assumptions used in the model are described in detail in Etkin (2004). The model can quantify relative damage and cost for different spill types, regarding regulatory-impact evaluation, contingency planning, and value assessment, relating to spill prevention and reduction measures.

BOSCEM incorporates spill-specific factors that influence cost: spill amount; oil type; response methodology, and effectiveness; resources affected; location specific socioeconomic value: freshwater vulnerability; habitat/wildlife sensitivity; and location type. Including these spill-specific factors to develop cost estimates provides a greater degree of accuracy in estimating oil spill costs than do the universal per gallon figures (derived from historical data) that are traditionally used to estimate costs. The model's basic structure allows response methodologies (dispersants and in-situ burning, for example) to be specified. In also allowing response effectiveness to be specified, it enables the potential benefits of modifying the response scenario to be analyzed (e.g., introducing a new technology).

A Web-based analytical tool, OSRCEAT, was developed by ERC to compare costs-of-response to benefits-of-response for hypothetical or actual oil spills. The OSRCEAT model is described in detail in Etkin (2005b). OSRCEAT can assist spill responders and contingency planners in decision-making processes, and act as a basis of discussion for evaluating response options. Using user input on spill parameters, location, and response options, OSRCEAT calculates response cost, the cost of the environmental and socio-economic impacts of spilled oil, and response impacts (damages caused by response activities).

Oil damages without any response are contrasted to oil damages with response (improvements that response offers). Response damages are subtracted from the difference in damages with response and without response to derive an overall response benefit. Response cost can then be compared to response benefit. The user can test various response options to compare potential response benefits, toward maximizing response benefit. OSRCEAT is best used to compare and contrast the relative benefits and costs of various response options.

The basic premise of the calculations is that the baseline of oil damages without response (that is, the damage to natural and socioeconomic resources that would have occurred from the oil in the

absence of any form of response) are compared to the oil damages remaining despite response efforts and the damages that the response itself might cause, so that:

Oil Damage Without Response − Oil Damage With Response − Response Damage = Response Benefit.

The objective is to derive the benefit, if any, of the response. After calculating response cost, the user can then compare response cost to response benefit to derive a cost-to-benefit ratio of the response.

5.2 Results of Statistics-based Cost-Savings Analysis

ERC conducted a cost-savings analysis on heavy oil spills occurring during 1995-2004 to determine the increased response effectiveness that might have been realized if LF technology had been employed to detect and track the spilled oil. Using the ERC BOSCEM model, ERC determined the potential differences in spill response costs, and in environmental and socioeconomic damages, for individual spills, with the change in spill-response timing and effectiveness being attributed to LF. The results are summarized in Table 16.

Table 16. Estimated costs for heavy oil spills of 500 gallons or more into U.S. navigable waters 1995-2004 with use of LF technology (based on ERC BOSCEM).

Year	Response Costs (M) [1]				Environmental Damages (M)[1]				Socioeconomic Damages (M)[1]			
	None[2]	2 hours[3]	24 hours[4]	72 hours[5]	None	2 hours	24 hours	72 hours	None	2 hours	24 hours	72 hours
1995	$97	$63	$82	$92	$23	$15	$20	$22	$146	$95	$124	$139
1996	$63	$41	$53	$59	$10	$6	$8	$9	$55	$35	$46	$52
1997	$64	$41	$54	$60	$15	$9	$12	$14	$104	$68	$89	$99
1998	$76	$49	$64	$72	$14	$9	$12	$14	$88	$57	$74	$83
1999	$153	$99	$130	$145	$19	$12	$16	$18	$91	$59	$77	$86
2000	$68	$44	$58	$64M	$12	$8	$11	$12	$76	$49	$64	$72
2001	$7	$5	$6	$7M	$2	$1	$2	$2	$11	$7	$9	$11
2002	$11	$7	$9	$10M	$3	$2	$2	$3	$18	$11	$15	$17
2003	$39	$26	$33	$37M	$6	$4	$5	$6	$63	$41	$53	$60
2004	$42	$27	$36	$40M	$13	$9	$11	$12	$57	$37	$48	$54
Total	$620	$402	$525	$586	$117	$75	$99	$112	$709	$459	$599	$673

Table Notes:
(1) Costs adjusted to 2004 dollars.
(2) No LF technology employed.
(3) LF technology employed in the first two hours.
(4) LF technology employed in the first 24 hours.
(5) LF technology employed after the first 72 hours.

In this analysis, it was assumed there would be an increase in response effectiveness (oil removal capability), due to the ability to respond at night, and the ability to more accurately track the movement and location of oil. The estimated efficiency of oil removal was based on previous consultations with Spiltec, Inc., during a study conducted for the Washington Department of Ecology (WDOE), as described in Etkin et. al., (2005). Oil spill responses without the benefit of LF technology were assumed to have an oil removal efficiency averaging ten percent. With the benefit of the technology at two hours, the response was assumed to have 45 percent effectiveness, at 24 hours 25 percent, and at three days 15 percent.

Using these assumptions, the BOSCEM model provides the cost savings associated with employment of LF technology at 2, 24 and 72 hours, as summarized in Table 17 below. When totaled, the cost savings in Table 17 for the ten-year period from 1995 to 2004 indicate that $510M would be saved if LF technology were made available within 2 hours; $223M, if made available within 24 hours; and $75M, if made available within 72 hours. The cost savings figures in Table 17 are based on 2004 dollars. Adjusting these figures to 2006 dollars (increasing the figures by five percent) produces cost savings of $535M for 2 hour LF availability, $234M for 24-hour LF availability, and $79M for 72-hour LF availability. These figures translate into an annual average cost savings of $53.5M for introducing LF at 2 hours; $23.4M for introducing LF at 24 hours; and $7.9M for introducing LF at 72 hours if all costs are considered.

Table 17. Estimated cost savings for heavy oil spills of 500 gallons or more into U.S. navigable waters 1995-2004 with use of LF technology (based on ERC BOSCEM).

Year	**Response Costs (M) [1]**				**Environmental Damages (M)[1]**				**Socioeconomic Damages (M)[1]**			
	None[2]	**2 hours[3]**	**24 hours[4]**	**72 hours[5]**	**None**	**2 hours**	**24 hours**	**72 hours**	**None**	**2 hours**	**24 hours**	**72 hours**
Total Cost	$620	$402	$525	$586	$117	$75	$99	$112	$709	$459	$599	$673
Cost Savings	$0	$218	$95	$34	$0	$42	$18	$5	$0	$250	$110	$36

Table Notes:
(1) Costs adjusted to 2004 dollars.
(2) No LF technology employed.
(3) LF technology employed in the first two hours.
(4) LF technology employed in the first 24 hours.
(5) LF technology employed after the first three days.

With respect to response costs alone, Table 17 indicates that $218M would be saved for 2 hour LF availability, $95M for 24 hour LF availability, and $34M for 72 hour LF availability over a ten year period. Adjusting these figures to 2006 dollars produces response cost savings of $228M for 2-hour LF availability, $99M for 24 hour LF availability, and $36M for 72-hour LF availability over a ten year period. This produces annual response cost savings of $23M for introducing LF at 2 hours; $10M for introducing LF at 24 hours; and $3.6M for introducing LF at 72 hours. These results assume the LF capability would be used during all heavy oil spills, with a positive impact, which, of course, is not likely to be the case.

For the OSRCEAT model predictions, it is assumed that LF technology is inserted into the spill response effort at 12 hours. To the extent possible, specific input data for each of the 115 spills analyzed were inserted into the OSRCEAT program. When no definitive data were available, default values were used for such variables as water temperature, wind speed and direction, shoreline types, and socioeconomic and natural resource features.

The important assumptions that were employed in these calculations are:

- No Fluorosensor: Responses were assumed to be ten percent effective in removing oil.

- Fluorosensor at 12 Hours: Responses were assumed to be 33 percent effective, based on Figure 13. The effectiveness values in Figure 13 are based on the assumed effectiveness ratings used in the ERC BOSCEM modeling described above. Using the same values makes the assumption for the two modeling approaches roughly equivalent. Points for two hours, 24 hours, and 72 hours were the assumed effectiveness percentages incorporated into the ERC BOSCEM model.

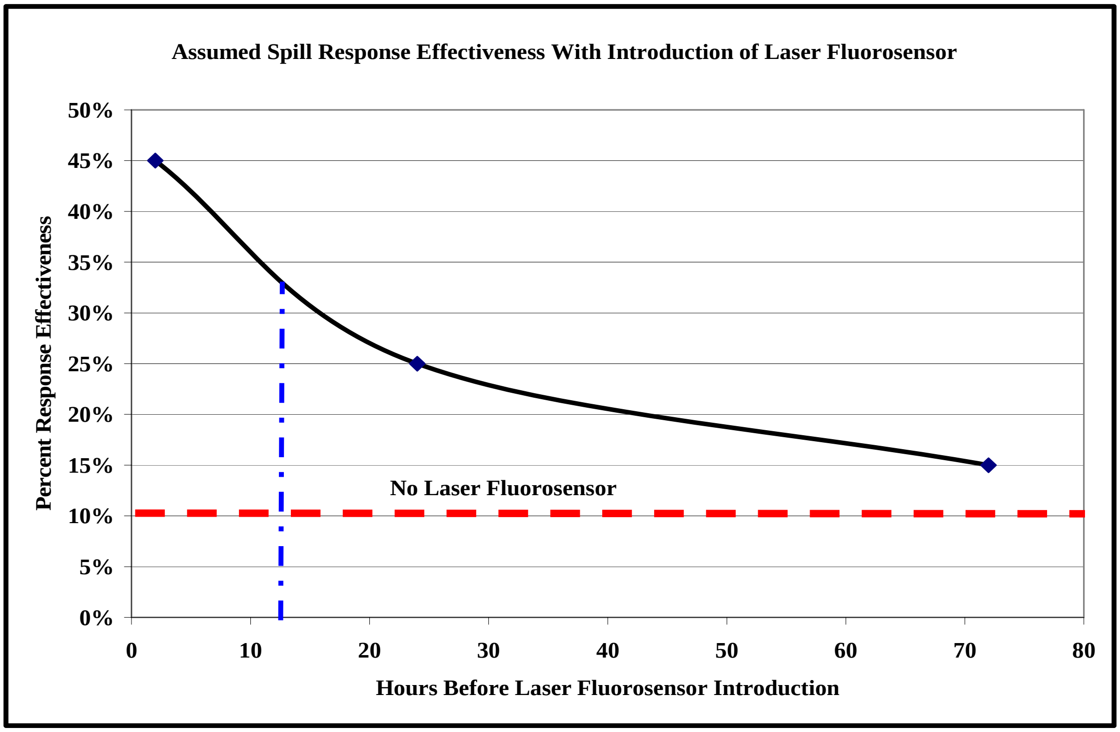

Figure 13. Assumed spill response effectiveness with introduction of LF.

- Spill responses for both “No Fluorosensor” and “Fluorosensor at 12 Hours” were assumed to begin at 12 hours for coastal, near-shore, and river spills. Spill responses for offshore spills were assumed to begin at 24 hours, as per USCG response planning standards. For offshore spills, LF was assumed to aid in locating the oil before response operations began.

- Spill responses were assumed to be limited to on-water mechanical containment and recovery, with appropriate shoreline cleanup.

Modeling results are shown in Table 18 and Table 19, and Figure 14 and Figure 15. The composite results suggest that the estimated annual savings from using LF at 12 hours is about $40M per year, including $10M in response costs, $9M in environmental damages, and $21M in socioeconomic damages. Again, these results assume that the LF capability would be used during all spills. Adjusting these figures to 2006 dollars provides estimated annual savings of $42M including $10.5M in response costs, $9.5M in environmental damages and $22M in socioeconomic damages.

Table 18. Estimated costs for heavy oil spills of 500 gallons or more into U.S. navigable waters 1995-2004 with use of LF technology (based on ERC OSRCEAT).

	Response Costs (M)		**Environmental Damages (M)**		**Socioeconomic Damages (M)**	
	No Fluorosensor	**Fluorosensor at 12 hours**	**No Fluorosensor**	**Fluorosensor at 12 hours**	**No Fluorosensor**	**Fluorosensor at 12 hours**
1995	$64	$54	$67	$56	$109	$80
1996	$62	$51	$62	$51	$93	$68
1997	$40	$33	$42	$35	$67	$50
1998	$50	$41	$52	$43	$82	$60
1999	$200	$160	$166	$137	$211	$152
2000	$47	$39	$49	$41	$78	$57
2001	$6	$6	$6	$5	$11	$8
2002	$8	$7	$9	$7	$16	$12
2003	$27	$22	$27	$22	$39	$28
2004	$58	$47	$53	$44	$70	$51
Total	$562	$460	$533	$441	$776	$565
Average	$56	$46	$53	$44	$78	$57
SD	$55	$43	$45	$37	$57	$41

Table 19. Estimated annual savings using LF for spill response (based on OSRCEAT cost estimates).

Year	Total Annual Savings (2004 Dollars)			
	Response (M)	Environmental (M)	Socioeconomic (M)	Total Savings (M)
1995	$10	$11	$29	$50
1996	$11	$11	$25	$47
1997	$7	$7	$17	$31
1998	$9	$9	$22	$40
1999	$40	$29	$59	$128
2000	$8	$8	$21	$37
2001	$0	$1	$3	$4
2002	$1	$2	$4	$7
2003	$5	$5	$11	$21
2004	$11	$9	$19	$39
TOTAL	$102	$92	$210	$404
Average	$10	$9	$21	$40
SD	$11	$8	$16	$35

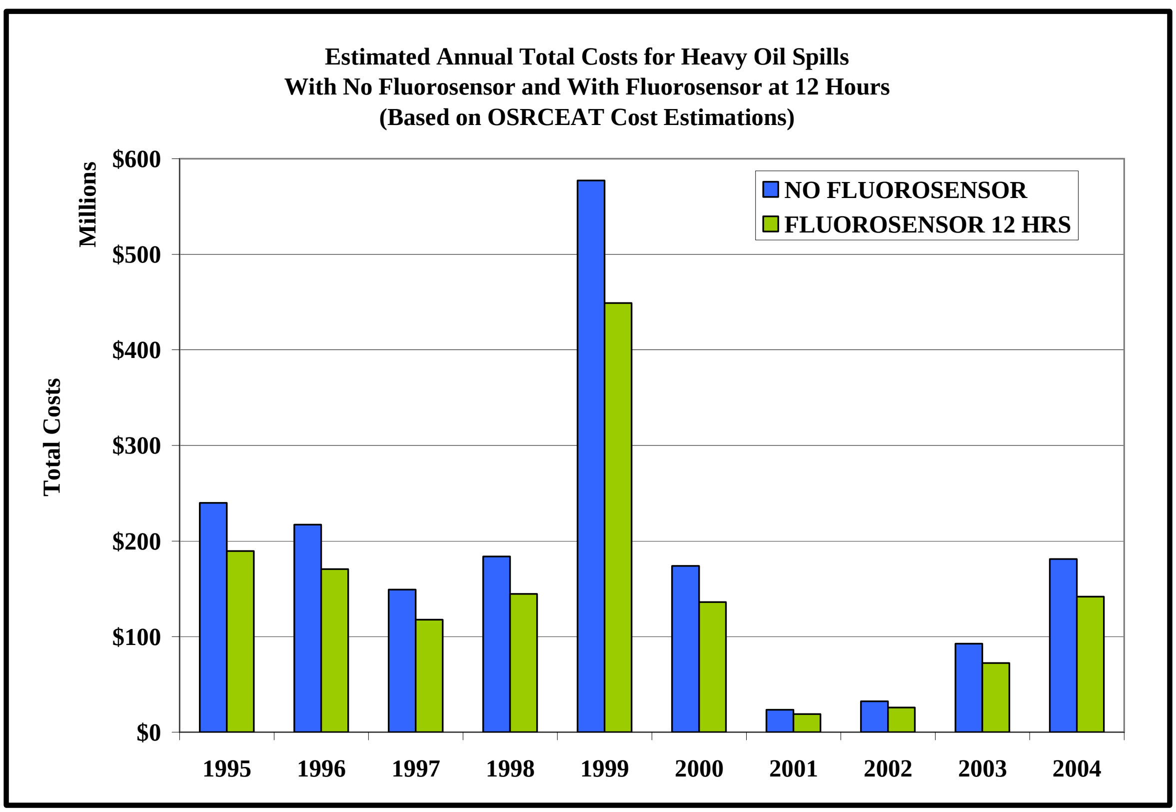

Figure 14. Estimated total costs for heavy oil spills with no LF, and with LF at 12 hours.

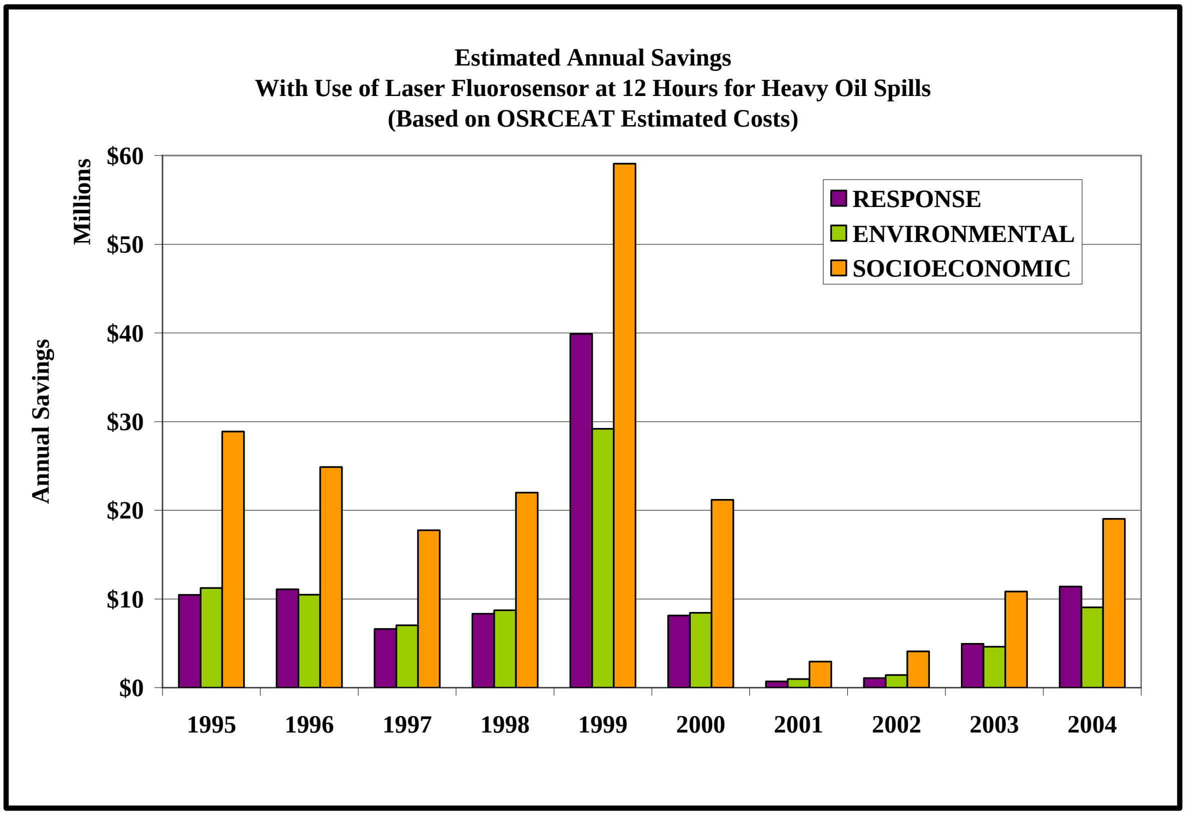

Figure 15. Estimated annual savings from using LF at 12 hours for heavy oil spills.

In interpreting the cost savings predicted by the BOSCEM and OSRCEAT cost savings models, it is important to note that these values are based on statistical cost data (dollars per gallon for oil cleaned up, as well as environmental and socioeconomic damages incurred, by oil type) applied to the volume of oil spilled in any given year. Because of this, the predicted cost and cost savings data may not correspond to the actual oil spill cost figures recorded for a series of spills in any given year. It is also important to note that the cost savings obtained from the BOSCEM and OSRCEAT models are highly sensitive to the spill response effectiveness assumptions inherent in the response effectiveness curve in Figure 13. For any given spill, the position and shape of the response effectiveness curve could vary significantly from the generalized curve in Figure 13. Accordingly, the cost savings values generated by BOSCEM and OSRCEAT should be viewed as rough order of magnitude (ROM) estimates.

6. COST OF IMPLEMENTING A LF CAPABILITY IN THE USCG

There are a number of potential uses for the LF in supporting USCG missions. These include: (1) providing on-scene intelligence about oil location and the area contaminated during responses to larger spills; (2) providing shipboard oil-pollution surveillance and enforcement; and (3) possibly providing for the detection and identification of chemical spills and releases of other hazardous materials (for example, chemical and biological warfare agents). This analysis concentrates on the first of these mission applications, as support during response operations was the focus of the LF benefits analysis previously described in Sections 4 and 5.

6.1 Concept of Operations for the LF System

In supporting oil spill response operations, airborne spill surveillance is employed at two levels: strategic and tactical. Strategic surveillance, which includes wide area detection and mapping, is used to define the overall area impacted by the spill and the general movement of the spill. This is accomplished primarily through visual observations when possible or using electronic remote sensing systems when available. The strategic remote sensing systems are effective at higher altitudes and airspeeds that cover a swath on either side of the aircraft up to several hundred meters in width. At present, sensors such as Side-Looking Airborne Radar (SLAR), Synthetic Aperture Radar (SAR), Ultraviolet (UV) and Infrared (IR) Line Scanners, Microwave Radiometers (MWR) and Hyperspectral Imagers, are used for this purpose.

Each of these sensor systems has its advantages and disadvantages as described in detail by Lissauer and Robe (2004). For instance, radar systems (SAR and SLAR) are capable of detecting oil over a wide area of the ocean surface. However, because they detect oil by discriminating differences in the capillary wave signature of the ocean surface, they are ineffective at wind speeds of less than 3 knots or greater than 15 knots and corresponding sea states of less than 1 foot or greater than 5 feet. MWR and UV/IR sensors provide good coverage along a track up to 250 meters wide on either side of the aircraft but are also limited by environmental conditions. The UV and IR systems in particular are subject to false alarms as a number of other substances and conditions in the marine environment produce sensor signal returns similar to oil.

To overcome the inherent limitations of the individual sensors, strategic oil spill remote sensing systems usually include an integrated suite of several sensors to cross check for false alarms and enhance the overall picture of oil location and concentration provided. Accordingly, for purposes of strategic oil spill mapping and tracking, as well as general pollution surveillance (for example, enforcement of the International Convention for the Prevention of Pollution from Ships (MARPOL)), an LF system should be integrated with other sensors having an oil detection capability. This is the approach followed by several nations maintaining a strategic oil spill remote sensing capability including Great Britain, Germany, Sweden, and Norway (Lissauer and Robe, 2005). It should be noted that these European countries favor a strategic, fully integrated system because they routinely conduct oil pollution surveillance and enforcement patrols along their coastlines. For the USCG, surveillance is more often connected with an actual spill.

For the USCG such a system has included a SLAR, UV/IR line scanner, and low light level camera as in the original AIREYE system (integrated maritime remote sensing system installed in the USCG H-25 Guardian fixed-wing aircraft) of the 1980s and the Airborne Oil Spill Surveillance (AOSS) system of the early 1970s. These integrated systems are generally implemented aboard a medium-to long-range, fixed-wing aircraft with data analysis and display onboard the aircraft. Although the AIREYE system is no longer operational, the USCG currently maintains two HC-130 aircraft at Elizabeth City, NC that are equipped with SLAR and Forward-Looking Infrared (FLIR) sensors that would complement the LF employed in the strategic mode.

The second level of airborne oil spill remote sensing tactical surveillance involves locating, positively identifying, and quantifying specific oil concentrations, so that cleanup resources (for example, booms, skimmers, dispersant aircraft, and in-situ burning equipment) can be more

effectively deployed to remove/recover the oil. This type of surveillance generally involves smaller aircraft (fixed-wing or helicopter) flying at slower speeds and lower altitudes, with the ability to easily divert from the planned track to check out suspected oil concentrations. Currently, this capability for the USCG is provided by helicopters equipped with aircraft-mounted FLIR or handheld IR systems.

These small, portable FLIR units have become a primary remote sensing tool for tactical spill response. Profiling (non-scanning) versions of the LF, or scanning versions with a limited swath width (for example, 20 meters on either side of the aircraft), are likely to be employed in this mode. Within the USCG, a number of the HH-60 Jayhawk helicopters have been configured with aircraft-mounted FLIR systems mounted in a dome under the nose with real-time image display for the pilots. Handheld IR systems can be used aboard any USCG helicopter. The handheld systems provide the advantage of portability; however, they may be difficult to hold over longer periods of time and do not allow data capture and automatic correlation with the aircraft's position.

In assessing the potential benefits of the LF in improving spill response effectiveness and reducing cost, it appears that much of the required surveillance would be tactical in nature, particularly in locating and quantifying sunken oil or oil dispersed in a marsh or along a shoreline. Therefore, this tactical capability becomes important, and should be included in the overall Coast Guard oil spill remote sensing capability. This suggests two possible concepts of operations and implementation options for LF in the USCG.

The first approach would be to include an LF capability as part of a multi-sensor system. The system would be flown at a higher altitude (for example, 2000 feet) using the SLAR and FLIR sensors to determine the general location of the spill and identify areas where the greater concentrations may exist. The aircraft would then fly at lower levels (for example, 500-1000 feet) using the LF to confirm the presence of oil, determine the dimensions of the slick, and estimate the quantity present.

The second approach would be to utilize the fixed-wing aircraft with the wide-area SLAR and FLIR sensors to locate and map the spill at a strategic level, and then deploy the smaller fixed-wing or helicopter with the LF (and perhaps also the FLIR) at the tactical level to confirm the presence of oil and provide information on oil coverage, quantity, and physical state to the On-Scene Coordinator (OSC) for cleanup operations management.

6.2 Implementation Options

The current configuration of USCG aircraft and the availability of the LF sensors and supporting aircraft outside of the USCG suggest four possible options for implementing the LF sensor capability. The first of these approaches (Option 1) is to incorporate the LF capability into an integrated USCG oil spill remote sensing system similar to those implemented in Germany, Sweden, Great Britain and Norway. Lissauer and Robe (2005) have estimated that configuring such a system would cost between $2.1M to $3.2M (excluding the cost of the aircraft and operating personnel). This approach is the one that has been traditionally adopted by the USCG as implemented in the AOSS system of the 1970s and the AIREYE System of the 1980s and 1990s. These systems were implemented aboard the medium-endurance fixed-wing aircraft of the day: the HU-16 Albatross for the AOSS, and the HU–25 Guardian for the AIREYE.

The advantage of this approach is that it allows one asset to provide oil spill surveillance for both initial detection and identification, and reconnaissance and tactical support during actual spills. It also centralizes the operation and maintenance of the integrated system to a few aircraft and aircrews. However, there are two fundamental problems associated with this approach. First, it makes the system platform a dedicated oil spill surveillance asset limiting its capability to perform other missions. This runs contrary to the multi-mission philosophy for Coast Guard aircraft. In addition, the use of a fixed-wing aircraft somewhat limits the ability to fly at the slower speeds and lower altitudes in providing tactical support for oil spill response operations.

The logical USCG airborne platform currently available for this option is the HC-130H long-range surveillance aircraft currently configured with both SLAR and FLIR. The HC-130's range, slower speed, and payload capacity make it an ideal platform for extended strategic spill surveillance missions. The SLAR has been in service for a number of years and is utilized for iceberg surveillance by the International Ice Patrol.

Two HC-130s at Elizabeth City, NC are equipped with the SLAR. In addition to SLAR, twenty-seven HC-130s have been configured to accept the C-130 Airborne Sensor with Palletized Electronic Reconnaissance (CASPER) system, a modular optical/infrared sensor system where the sensors are mounted in a turret under the nose of the aircraft, and the control station is mounted on a pallet that can be moved from aircraft to aircraft. The sensor package includes an electro-optic wide color camera, an electro-optic narrow low light camera, and a forward-looking infrared (FLIR) sensor. Fourteen sensors and palletized control panels are distributed throughout the U.S. for quick installation in the twenty-seven HC-130s. Implementation of this system involved a retrofit of the HC-130 airframe similar to the modifications that would be required to install an LF sensor system in the HC-130.

The CASPER sensor capability was provided under a contract to Wescam, Inc. The cost of the sensors, palletized control panel and data processing system, and installation of the sensor pods on the HC-130s was $37M. The systems are supported under a service contract to Wescam costing $8400 per unit per year that provides 600 operational hours per unit (Personal communication, LCDR Wood (2006), Coast Guard Headquarters). Because the HC-130 has an endurance of 14 hours flying time, implementation of the LF capability might involve one aircraft on each coast (Atlantic and Pacific), and possibly one in Alaska.

Ideally, any LF sensor installed in the HC-130 would be configured so that it could be mounted in the existing port in the nose of the aircraft where the CASPER sensor turret is now installed. This would significantly reduce installation costs. Whether the LF output display could be integrated into the CASPER palletized control station remains to be determined.

Longer-term implementation of Option 1 would involve integrating an LF into the medium-range EADS CASA aircraft being acquired under the Deepwater Project. These aircraft will be outfitted with an Inverted Synthetic Aperture Radar (ISAR) and FLIR. Installation aboard the EADS CASA aircraft would likely involve a retrofit similar to the current CASPER FLIR system, as the EADS CASA acquisition is already well underway, and the USCG LF technology is still in the Research, Development Test and Evaluation (RDT&E) stage. At present, there are no oil spill surveillance specific systems planned for any of the Deepwater aircraft.

The second approach (Option 2) is to separate the strategic and tactical oil spill surveillance roles. This approach would rely on the current SLAR and FLIR equipped HC-130s to provide a strategic oil spill mapping, tracking and surveillance capability; and utilize a medium- to short-

range airborne asset equipped with a FLIR and LF sensor capability to provide the tactical oil spill reconnaissance in support of oil spill cleanup operations. The logical aircraft currently available for implementation of this option is the HH-60 Jayhawk helicopter.

A number of the HH-60s have already been retrofitted with a turret-mounted FLIR system similar to the CASPER system with direct image presentation to the pilot. Implementation of an LF sensor capability would most likely require a similar retrofit to the HH-60, but with data presentation to a portable control station in the cabin where a trained LF data analyst would view and interpret the data. As the range of the Jayhawk helicopter is less than that of the HC-130, implementation of Option 2 would require that several helicopters be retrofitted and stationed on each coast at strategic locations to ensure a 12-hour response capability. Up to ten LF-capable HH-60s might be required (for example, stationed at Coast Guard Air Station (CGAS) Cape Cod, CGAS Atlantic City, CGAS Elizabeth City, CGAS Miami, CGAS Mobile, CGAS Corpus Christi, CGAS San Diego, CGAS Sacramento, CGAS Port Angeles and CGAS Kodiak).

The scope and details of the LF retrofit would vary depending on which LF system is being installed. Whether the LF system would be installed permanently or be configured so that it would be portable and easily mounted on the HH-60 as needed has not yet been determined. However, a reasonable assumption is that ten helicopters could be modified to accept the system with the perhaps 3-5 complete systems available for rapid deployment around the country. Under this approach, a number of systems could be acquired and operated by the National Strike Force; deployed to the Atlantic, Gulf and Pacific Strike Teams; and calibrated and maintained under contract similar to the approach used for the CASPER FLIR. Under this concept, when needed, the nearest available LF system and preconfigured HH-60 would be vectored to a common location where the LF system would be installed.

The advantage of making the system portable for installation as needed is that it would reduce the amount of hardware that would be needed, and allow centralization of system maintenance and operation. The disadvantage is that the LF system would not be readily available for strategic oil spill detection and enforcement purposes (that is, wide-area surveys to detect and conclusively identify illegal discharges of oil).

A third approach (Option 3) to providing the capability would be to arrange for the LF to be provided by another government agency that maintains an LF sensor capability. The LF system would be provided in the event of a major incident. Several agencies in the U.S. and Canada operate these systems including the Environmental Protection Agency (EPA), NASA, NOAA, and Environment Canada. Environment Canada has the SLEAF oil spill remote sensing system which has detected oil spills during research flights. NASA has the Particulate Oceanographic Lidar (POC) System which has been tested for oil detection performance at the Minerals Management Service (MMS) OHMSETT facility (Oil and Hazardous Materials Simulated Environmental Test Tank). EPA and NOAA have LF systems that have been used for environmental research and surveying that may be adaptable to oil spill remote sensing.

Access to the LF capability could be negotiated via interagency agreement. The problem with this approach is that any access agreement is unlikely to ensure guaranteed availability in the event of a major spill. In addition, additional time is required for agency notification and mobilization. The only way for the Coast Guard to ensure immediate full-time availability to

meet the 12-hour response criterion is to maintain a USCG owned and operated LF sensor capability.

The fourth option (Option 4), in providing the LF capability, is to station a number of fully portable systems around the country configured to be mounted on aircraft-of-opportunity that could be made available during a spill response. To ensure portability, these systems would have to be small and compact and be easily mounted in an existing port or hatch with a simple bolt-on or clamp-on arrangement. The operators (for example, Strike Force personnel) would accompany the system to the aircraft. Because the system would be limited to operation on un-pressurized airframes (integration into a pressurized airframe requires extensive engineering, certification and installation fabrication), the airborne platform would likely be a smaller fixed-wing aircraft or helicopter, readily available in the commercial aviation community (for example, the de Havilland Twin Otter or Bell Ranger). Because the aircraft would undoubtedly not have additional sensors (except perhaps a handheld FLIR unit also provided by the USCG), this option addresses only the tactical oil spill surveillance mission. In addition, utilizing an aircraft-of-opportunity would require additional time for equipment transport and system installation even if the aircraft were modified to accommodate LF.

Table 20 below summarizes the four implementation options outlining the spill-surveillance functions addressed, the platforms involved, and the advantages and inherent disadvantages of each.

Table 20. Implementation options for a USCG LF capability.

	Option 1 Fully- Integrated USCG System	**Option 2 Separate USCG Tactical LF System**	**Option 3 Provided by Another Agency**	**Option 4 Portable System on Aircraft-of - Opportunity**
Function Addressed	Strategic surveillance and tactical reconnaissance	Tactical reconnaissance; Strategic surveillance provided by a separate USCG asset	Strategic surveillance	Tactical reconnaissance
Current Platform	USCG HC-130 fixed-wing	HH-60 helicopter	NASA, NOAA, or Environment Canada fixed-wing	Readily available commercial fixed-wing or helicopter
Future Platform	USCG EADS CASA fixed-wing	HH-60 helicopter	Fixed-wing	Readily available fixed-wing or helicopter
Advantages	Immediate availability; Centralized operation and maintenance	Provides excellent tactical support for spill response; Good geographic coverage	Does not tie-up USCG multi-mission assets	Does not tie-up USCG multi-mission assets; Good geographic coverage
Disadvantages	Requires dedicated USCG fixed-wing asset; Limits response time	Strategic surveillance function is not addressed	No guaranteed immediate availability; Additional notification and mobilization time	Strategic surveillance function is not addressed; No guaranteed immediate availability

6.3 Description of Representative LF Sensor Systems Currently Available

In order to fully understand how an LF capability might be implemented within the USCG, it is necessary to define the general characteristics of the systems that might be available. At present, the LF technology is still in the RDT&E phase for USCG purposes. However, the USCG R&DC has evaluated three systems to determine the performance characteristics in detecting oil on the surface of the water and in the water column. These systems are the Particulate Oceanographic Lidar (POC) System operated by NASA to measure biological and oceanographic features, the Fluorescent Lidar Spectrometer-Shipboard System (FLS-S) system produced by LDI[3], Inc., and the Ultraviolet Biological Trigger Lidar (UBTL) developed by Science and Engineering Services, Inc. (SESI).

The USCG R&DC evaluated all three systems at the MMS OHMSETT facility under simulated spill conditions. The results of these tests are provided in Fant and Hansen (2005 and 2006). All three systems exhibited the ability to detect oil on the surface and to a depth of one to two meters. The NASA POC and LDI^3 FLS system were operable under both daylight and nighttime conditions. Because the UBTL system relies on photon counting for detection, it was limited to nighttime conditions during the OHMSETT tests, but SESI has indicated that this limitation has been corrected.

In terms of physical configuration (size, weight, number of components, power requirements), the LDI^3 FLS system is larger and more complex than the UBTL and NASA POC systems. The FLS consists of a large sensor assembly feeding into a desktop PC or laptop. The version of the LDI^3 system tested at OHMSETT was configured for shipboard use (FLS-S), but airborne versions can be provided as well (FLS-AM and FLS-AU). The FLS-AM system is the more recent and more capable system. Because of its size, it would most likely be the model implemented aboard fixed-wing aircraft.

The UBTL system is more compact and lightweight (consisting of a smaller sensor assembly feeding into a laptop computer) and more amenable to helicopter deployment. The NASA POC is the lightest and simplest of the three systems, as it requires only one laser. These three systems provide "representative" physical characteristics of an eventual USCG LF system. They also provide representative acquisition and maintenance costs for the USCG system that will be examined in the next section of this report. The system attributes for each of these three systems are summarized in Table 21.

Another system developed and tested over the years is the Environment Canada Scanning Laser Environmental Airborne Fluorosensor (SLEAF), which is currently flown on a DC-3 fixed-wing aircraft. The system is described in detail by Lissauer and Robe (2004). This LF system provides a true scanning LF capability with a swath width of 200 m at an altitude of 600 m. However, the system in its current configuration is large and complex. As noted by Fant and Hansen (2005) during the OHMSETT tests, the difficulty and expense associated with a scanning versus a profiling LF are evident. Also, the need for a scanning capability is decreased by the availability of the SLAR and FLIR sensors. However, if a scanning LF is developed that is smaller and less costly, it would be a viable candidate for USCG implementation.

Table 21. System attributes for three LF systems evaluated by USCG.

System	NASA POC(1)	LDI^3 FLS-AM(2)	SESI UBTL(3)
Major Components	Laser Optics-scanner Detector PC and Laptop	Laser LIDAR Chiller Optics-telescope Cameras Power Converter PC Computer	Laser Detector Optics-mirrors and telescope Laptop
Size: Dimensions Volume	1.05 m X 0.39 m X 0.19 m 0.07 m^3	Lidar Unit: 1.66 m x 6.85 m x 1.00 m Chiller: 0.38 m x 0.62 m x 0.67 m 11.6 m^3 total	1.5 ft. x 1.5 ft. x 2.5 ft. 5.6 $ft.^3$ (0.21 m^3)
Weight:	62 kg	350 kg	25 kg
A/C Requirements Installation Ports Power Total Payload:	26 cm diameter port 8 A, 115 V, 60 Hz	20 x 20 cm down-look port 230, 50 Hz, 1Phase 375 kg.	Un-pressurized port or hatch Tripod mount with manual pan and tilt 1.5 ft. x 1.5 ft. x 2.5 ft.
Total System Cost	\$200K-\$300K(4)	\$500 K(2)	\$150K(5)
Installation Cost	\$10K per aircraft	Unknown(6)	\$1K per unit
Maintenance Cost	\$25K per unit/year	Unknown	\$20K per unit/year

Table Notes:

(1) System described in NASA (2005).
(2) System described in LDI^3 (2005).
(3) System described in Prasad, Blagojevic, Huang and Bufton (2005). Science and Engineering Services, Inc., Columbia, MD, 2005.
(4) Data supplied by NASA (2006), Personal communication with Jim Yungel, NASA/EG&G Wallops Island.
(5) Data supplied by SESI (2006), Personal communication with Jack Bufton.
(6) Because the FLS system is currently designed for shipboard use, it is difficult to determine realistic installation costs for an aircraft.

6.4 Approach and Assumptions for Estimating LF Sensor System Costs

In developing cost estimates for implementing the LF capability under Options 1 through 4 as described in Section 6.2, a consistent approach must be followed and a number of assumptions must be defined. The goal in the cost analysis is to develop an estimate as to what implementation of the LF sensor capability will cost over a ten-year life cycle and on an annual

basis for each option. This figure can then be compared with the annual cost-savings derived from the LF scenario-based and statistics-based benefits analyses described in Sections 4 and 5.

As part of this, a number of separate cost categories were addressed including:

- System acquisition cost;
- System integration and installation costs;
- Airborne platform costs;
- Recurring system maintenance costs;
- Operating personnel costs;
- Training costs.

The assumptions used in estimating each of these cost categories are summarized below. A more detailed discussion of how these assumptions were formulated for each of the separate cost categories listed above is provided in Appendix C. One key general assumption in determining a cost estimate for a number of the categories is the amount of time that the LF capability would actually be in use. The assumption for the Wescam CASPER contract is that up to 600 hours of FLIR availability is required for each aircraft. An estimate of 240 hours of availability is assumed (10 full days of availability) for each LF system because it will probably not be as heavily used as the FLIR. This also reflects the amount of time that might be involved in supporting a major spill response effort.

The assumptions used in computing the annual cost and total life-cycle (ten year) costs for each of the Implementation Options considered are listed below. The options considered are as follows:

- Option 1 – Implementation of a USCG-owned LF system on a USCG fixed-wing aircraft;

- Option 2 – Implementation of a USCG-owned LF system on a USCG rotary-wing aircraft;

- Option 3 – Contracting for the LF capability with another agency;

- Option 4 – Deployment of a USCG-owned portable LF system on a contracted aircraft-of-opportunity.

System Acquisition Costs

Option 1	$30K to $50K per year per system ($300K-$500K over ten years)
Option 2	$15K per year per system ($150K over ten years)
Option 3	$180K per year per system ($1.8M per system over ten years)
Option 4	$15K per year per system ($150K over ten years)

System Integration and Installation Costs

Option 1	For installation in three HC-130 aircraft, an installation cost of approximately $181K per aircraft over ten years (or $18K per aircraft per year).
Option 2	For installation in ten helicopters, an installation cost of approximately $104K per aircraft (or $10K per aircraft per year).
Option 3	System integration cost is included in the annual contract cost.
Option 4	A one-time cost of $10–15K per platform ($1–1.5K per year per platform).

Airborne Platform Costs

Option 1	Airborne platform cost of $200K per year (~ 20 percent of the total platform cost).
Option 2	Airborne platform cost of $180K per year (~ 25 percent of the total platform cost).
Option 3	Airborne platform costs are included in the annual contract costs.
Option 4	Airborne platform cost of $8K–$10K per day. This amounts to an airborne platform cost of $80K–$100K per year for a ten-day deployment.

Recurring Maintenance Costs

Option 1	$25K per year per system.
Option 2	$15K per year per system.
Option 3	Recurring maintenance costs are absorbed in the annual contract cost.
Option 4	$15K per year per system.

Operating Personnel Costs

Option 1	Personnel investment of approximately $14K per year per system.
Option 2	Personnel investment of approximately $6K per year per system.
Option 3	Operating personnel costs are included in the annual contract costs.
Option 4	Personnel investment of approximately $6K per year per system.

Training Costs

Option 1	$4K per year per system or $40K per ten-year system life-cycle.
Option 2	$2K per year per system or $20K per ten-year system life-cycle.
Option 3	Contractor training costs are included in the annual contract costs.
Option 4	$2K per year per system or $20K per ten-year system life cycle.

6.5 Summary of LF Sensor Capability Costs by Cost Category

The costs per year for each system estimated using the assumptions in Section 6.4, and the computations in Appendix C for the four implementation options described in Section 6.2, are summarized in Table 22 below.

Table 22. Annual cost by category of employing an LF capability.

	Option 1 Fully-Integrated USCG System	**Option 2 Separate USCG LF System**	**Option 3 Provided by Another Agency**	**Option 4 Portable System on Aircraft-of - Opportunity**
LF System Acquisition Cost	$30–$50K per system per year	$15K per system per year	$180K per system per year	$15K per system per year
Integration and Installation Cost	$18K per system per year	$10K per system per year	$1K per system per year	$1–1.5K per system per year
Airborne Platform Costs	$200K per year	$180K per year	N/A	$80–100K per year
Recurring Maintenance Costs	$25K per system per year	$15K per system per year	N/A	$15K per system per year
Operating Personnel Costs	$14K per system per year	$6K per system per year	N/A	$6K per system per year
Training Costs **Instruction** **Aircraft Time**	$4K per system per year $40K per system per year	$2K per system per year $36K per system per year	N/A	$2K per system per year $20K per system per year
Total Annual Cost	$330–$350K per system per year	$260K per system per year	$180K per system per year	$140–$160K per system per year

6.6 Estimated Total Cost of Providing the LF Sensor Capability to the USCG

To compute the total cost of providing the LF sensor system capability to the USCG, the costs in Table 22 for each implementation option must be multiplied by the number of systems required to provide the 12-hour response time. The only category that this does not apply to is the airborne platform cost that is an annual figure. For Option 1 (Multi-Sensor Integrated System aboard an HC-130), it is assumed that two systems would be required: one on each coast (East and West). For Option 2, it is assumed that four systems would be deployed (one with each USCG Strike Team and another in Alaska) with ten HH-60 helicopters outfitted throughout the country to interface with the LF sensor system. For Option 3, it is assumed that a contracted system would have to be available on each coast. For Option 4, it is assumed that four systems would be deployed (one with each Strike Team and another in Alaska).

Using the number of systems for each option, and performing the required multiplication produces the total costs for LF implementation over a ten-year period. These costs are provided for each option as presented in Table 23.

Table 23. Total costs over 10 years for LF implementation option.

	Option 1 Fully-Integrated USCG System	Option 2 Separate USCG LF System	Option 3 Provided by Another Agency	Option 4 Portable System on Aircraft-of - Opportunity
Number of Systems	2	4	2	4
LF System Acquisition Cost	$660K–$1M	$600K	$3.6M	$600K
Integration and Installation Cost	$362K	$412K	$20K	$40–$60K
Airborne Platform Costs	$2M	$1.80M	N/A [1]	$0.8–$1.0M
Recurring Maintenance Costs	$500K	$600K	N/A [1]	$600K
Operating Personnel Costs	$280K	$240K	N/A [1]	$60K
Training Costs **Instruction** **Aircraft Time**	 $80K $800K	 $80K $1.4M	N/A [1]	 $80K $800K
Total Cost	$4.68M–$5.02M	$5.13M	$3.62M	$2.98–$3.20M

Note: 1) Costs for this category are included in the system acquisition cost above.

The total cost data in Table 23 show that Options 1 and 2 which involve implementation of a USCG-owned and operated LF system aboard USCG airborne platforms are more expensive than relying on a fully-contracted capability (Option 3) or a USCG-owned LF system deployed on commercial aircraft-of-opportunity (Option 4). The primary trade-off between Options 1 and 2 versus Options 3 and 4 is guaranteed availability when the system is required.

Option 1 has an advantage over Option 2 in that it is part of a multi-mission surveillance sensor capability (applicable to other missions as well as oil spill response), and is, therefore, more likely to be deployed on a regular basis for both training and response. This frequency of use is an important issue in maintaining the capability over a longer period of time. One reason why the AOSS and AIREYE systems were not continued is that they were infrequently used. During periods of declining USCG operational budgets, such systems are likely to be discontinued.

Option 2 provides a capability that is more useful in providing tactical support during an actual spill response effort. The major unknown variable for Option 2 is the retrofit costs to allow the HH-60 to accommodate the LF system. For Options 3 and 4, the advantage is apparent cost savings, but availability in an emergency, and the contractual arrangements and costs required to ensure availability, may increase costs such that Options 3 and 4 become equivalent in cost to Options 1 and 2. Viewed together, Options 1 through 4 suggest that providing an LF sensor capability to the USCG will cost from \$3M to \$5M over ten years or \$300K to \$500K per year.

7. CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

The final step in the cost-benefit analysis is to compare the cost savings that might be gained by implementing an LF capability against the anticipated cost of acquiring, operating, and maintaining the capability. To begin with, the cost savings must be addressed.

Cost savings estimates were computed by means of the scenario-based modeling approach, and also by means of the statistics-based modeling approach. The next logical step is to determine if there is some measure of consistency between the two sets of estimates. The scenario-based approach, using the SIMAP model, indicates a representative cost savings for a large heavy oil spill of \$5M to \$15M. A conservative estimate on the frequency of occurrence of heavy oil spills of this nature and magnitude is perhaps once every five years. Together, these estimates suggest a potential annual cost savings in all cost categories of \$1.0M to \$3.0M per year. For response costs alone, the cost savings might be \$0.5M to \$1.0M per year.

The BOSCEM model indicates that \$535M would be saved over ten years if LF technology is made available within two hours; \$234M would be saved if LF technology is made available within 24 hours; and \$79M would be saved if LF technology is made available within 72 hours of the spill. On an annual basis, this translates into a savings of \$53.5M per year if the LF is made available within two hours, \$23.4M if it is made available within 24 hours, and \$7.9M if it is made available within 72 hours. These results assume that LF capability would be used during all spills, with a positive impact. If an LF capability were employed on only 20 percent of all heavy oil spills, the annual cost savings becomes approximately \$10M per year if LF is made available within two hours, \$5M if it is made available within 24 hours, and \$1.5M if it is made

available within 72 hours. If only response costs are considered, the annual cost savings are $23M for introducing LF at two hours; $10M for introducing LF at 24 hours; and $3.6M for introducing LF at 72 hours. Assuming application of the LF to 20 percent of the heavy oil spills that occur, the cost savings for response alone become $5M for LF application at two hours, $2M for application at 24 hours and $0.7M for application at 72 hours.

The OSRCEAT model indicates that employment of an LF capacity at the 12-hour mark of a spill would save $42M per year, including $10M in response costs, $9.5M in environmental damages, and $22M in socioeconomic damages. Again, this result assumes that LF is used on all 115 spills. If it were only used on 20 percent of these spills, the cost savings in all categories would be decreased to $8M per year. For response costs alone, the cost savings for application of the LF at 12 hours would be $2M per year.

Taken together, the two approaches (Scenario-based and Statistics-based) suggest an annual cost savings of $1M to $10M per year, depending on when the LF capability comes into play (2 to 72 hours after the spill), and on the enhanced effectiveness (greater percentage of oil recovered) the capability provides. If LF is employed 12 to 24 hours after a spill (which is more likely), the annual cost saving would be approximately $5M to $8M for all cost categories. The cost savings for response costs will be on the order of $0.5M to $2.0M per year depending on when the LF arrives on-scene, and how effective response operations are without the LF.

It is also clear that a significant portion of the cost savings are in spill response costs, particularly for the larger spills involving extensive shoreline cleanup efforts. This point is significant in that these cost savings most directly relate to the USCG by indicating a reduced level of effort by the FOSC and potentially reduced charges to the Oil Spill Liability Trust Fund. It is precisely these cost savings that could justify an expenditure of USCG funds to acquire, operate, and maintain an LF capability. NRD cost savings and socioeconomic cost savings accrue to third parties, and are less likely to justify a direct expenditure of USCG funds for a mission-specific system.

Table 23 indicates that the cost of implementing an LF capability ranges from roughly $0.3M to $0.5M per year, depending on the implementation option chosen. The more expensive options are Options 1 and 2, a USCG-owned system deployed either on a USCG fixed-wing aircraft or on a helicopter. These two options cost approximately $0.5M per year, but ensure immediate availability. The least expensive options are the two contracted options, Option 3 and 4. These options cost approximately $0.3M per year but do not guarantee immediate availability.

It should be noted that the cost estimates provided for Options 1 and 2 for LF system acquisition are based on ROM (rough order of magnitude) estimates provided by LF sensor system developers. Installation and operation costs are based on a number of assumptions on the configuration, deployment and level of usage for the systems. These costs could vary significantly depending on the LF system ultimately chosen and the specific installation required in the USCG fixed-wing aircraft or helicopter. For a relatively simple sensor system integrated to a portable computer-based data processing system, where the installation is accomplished using an existing sensor port (e.g., the sensor pod for the current CASPER system), the $0.5M per year estimate is probably realistic. However, for a more complex system requiring a palletized control panel and further modification of the aircraft, the cost may be significantly higher.

Overall, the model-based cost-benefit analysis undertaken in this study indicates that costs and benefits for the LF are roughly equal when viewed on an annual basis. However, there are several other factors that should be taken into consideration. First of all, concern within the U.S. for oil pollution is not driven by annual spill volumes, or even by the number of spills over 500 gallons. Instead, it is driven by the occurrence and response to "spills of national significance." These spills often involve serious maritime casualties; release of millions of gallons of oil; and lead to substantial response; natural resource damage and socioeconomic costs. Of the spills considered in the scenario-based analysis, the Strait of Juan de Fuca involving one million gallons of Bunker C released in an environmentally sensitive area represents such a spill. The results presented in Table 15 indicate that a cost savings of up to $10M might be realized if the LF capability were available within 24 hours of the spill. In addition, public opinion would more likely be favorable if the USCG responders are able to effectively detect, identify and recover at least a portion of the spilled oil.

Another factor to consider is that this cost-benefit analysis has focused on the impact of the LF on oil spill response. Other applications of the LF technology including chemical spill response (to both accidental and intentional spills) and enforcement of oil pollution regulations (for, example, MARPOL enforcement) have not been considered. Use of the LF capability in these applications may accrue cost-savings as well. In particular, pollution surveillance and enforcement is more likely to provide benefit on a regular basis. Finally, an ongoing R&D project to utilize laser systems to mark and track suspect vessels is also a closely related application.

7.2 Recommendations

The results of the study clearly indicate that the annual costs of implementing the LF capability are comparable to the anticipated benefits. However, the project team does not recommend that the USCG go forward with a major LF systems acquisition and implementation program based on cost savings alone. This recommendation is supported by the fact that the LF systems being considered by the USCG are still somewhat developmental in nature, having been originally designed for other research and survey applications. As these systems mature and the acquisition costs are reduced, the cost-benefit ratio is likely to become more favorable.

The results of Section 6 show that either contracting for both the LF system and platform from another agency (Option 3), or deploying a USCG-owned and operated sensor on an aircraft-of-opportunity (Option 4), is the less costly option. This approach would not involve a substantial long-term commitment of USCG assets and would allow the LF system to be used on spills of opportunity to further demonstrate the performance and benefits of the LF technology. Accordingly, Options 3 or 4 should be investigated as a potential interim step in providing an LF capability. Under these two options, one or more of the currently available systems could be configured and made available for on-scene testing during a spill response effort.

Concurrently, the USCG should continue to support the development, refinement, and testing of LF sensors. Development should focus on improving the ability of the sensors to penetrate the water column to detect oil on and near the bottom where it may ultimately collect. Engineering refinements should address reducing the size and weight of the sensor systems to facilitate rapid deployment aboard aircraft-of-opportunity (either USCG, other government agency or commercial).

Finally, other applications of the LF, such as oil pollution surveillance and enforcement; detection of hazardous chemical spills; detection and possibly identification of chemical and biological agents, should be investigated. These applications might provide additional benefits and justification for the acquisition of a USCG-owned and operated system aboard USCG aircraft.

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APPENDIX A.

SPILLS CONSIDERED IN THE COST-BENEFIT ANALYSIS

One hundred fifteen (115) heavy oil spills of 500 gallons and greater, and occurring between 1995 and 2004, were analyzed in the Opportunities Analysis (described in Section 3 of the main body of the report), and formed the basis for the Statistics-Based Cost-Savings Analysis (described in Section 5 of the main body of the report). Table A-1 identifies these spills and provides the basic characteristics for each.

In determining viable candidate spills for the Scenario-based Cost-Savings Analysis, 15 heavy oil spills occurring between 1984 and 2004 were examined in detail as described in Section 4.1. These fifteen spills are discussed below (this information is from a December 2005 report).

T/B MORRIS J. BERMAN

<u>1/7/1994: 798,000 Heavy No. 6 fuel, San Juan, Puerto Rico</u>.

The spill was well documented and did involve No. 6 oil that sank. The spill was wind and wave driven which makes trajectory modeling possible. There are good cost data available on the spill. However, for the most part spill responders already knew where the oil was located. Therefore, it is unlikely that the laser fluorosensor would have made a significant difference in the outcome of the spill.

T/V CAPE MOHICAN

<u>10/28/1996: 98,000 gallons of No. 6 fuel, San Francisco Bay, CA.</u>

This was a No. 6 fuel oil spill in San Francisco Bay that originated in a dry dock. Only about half of the 98,000 gallons spilled (44,100 gallons) actually entered the water. The oil was initially confined to the dry-dock area but eventually migrated out of the dock area and drifted north and south in San Francisco Bay. Detection was an issue. Because of previous work, ERC and ASA have good trajectory, environmental and cost data for San Francisco Bay.

T/V EXXON VALDEZ

<u>3/24/1989: 11 million gallons of ANS crude, Prince William Sound, AK.</u>

Plenty of oil and spill response information, but finding oil to clean up was not an issue. It is unlikely that the LF would have had a significant impact on the outcome of the spill.

T/V COMMAND

<u>9/28/1998: 51,450 gallons of No. 6 fuel, off San Francisco Bay, CA.</u>

This spill was caused by a hose coupling failure during a transfer procedure from the T/V Command. It was originally reported by a fishing boat traveling through the slick left by the tanker at night. There was a significant cleanup effort associated with the spill which came ashore south of San Francisco Bay along the coast. Although the oil did not sink, detection at night was an issue.

Table A-1. Heavy oil spills of at least 500 gallons into U.S. navigable waters 1995-2004[1].

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
1/27/95	Longview	WA	Columbia River	Weyrhauser	Facility	No. 6 Fuel	1,000
2/15/95	Port O Connor	TX	Gulf Of Mexico Coastal	Berge Banker	Tank Ship	No. 6 Fuel	37,716
2/24/95	Hamakua	HI	N Pacific Ocean	Hamakua Sugar Co.	Facility	No. 6 Fuel	11,000
2/27/95			Gulf Of Mexico 12-200 Miles	Florida Express	Tank Ship	No. 6 Fuel	8,400
2/28/95	Port Arthur	TX	Sabine/Neches River	Anthos	Freight Ship	No. 6 Fuel	840
3/7/95	Neah Bay	WA	Strait Of Juan De Fuca	Unknown Vessel	Unclassified Vess.	No. 6 Fuel	634
3/14/95	Long Beach	CA	Pacific Ocean	OOCL Flame	Other Vessel	No. 6 Fuel	29,000
3/31/95	Wilmington	CA	Port Los Angeles/Long Beach	WT. 30	Tank Barge	No. 5 Fuel	1,250
6/23/95	Staten Island	NY	Arthur Kill	Bloxom	Unclassified Vessel	No. 6 Fuel	4,500
7/1/95	Venice	LA	Gulf Of Mexico Contiguous	Enif	Freight Ship	No. 6 Fuel	92,610
7/19/95		AL	Theodore Industrial Canal		Facility	Heavy Fuel	1,200
7/19/95	Theodore	AL	Navigable Waters	Donald Duckling	Freight Ship	No. 6 Fuel	5,000
8/5/95	Portland	OR	Willamette River	Norton	Tank Barge	No. 6 Fuel	1,800
8/8/95	Grand Haven	MI	Grand River/Lake Michigan	Grand Haven Light & Power	Facility	No. 5 Fuel	551
8/8/95	Houston	TX	Houston Ship Channel	NMS-3100	Tank Barge	No. 6 Fuel	1,250
8/17/95	Rumford	ME	Androscoggin River	Boise Cascade Papermill	Facility	No. 6 Fuel	1,000
9/5/95	New Orleans	LA	Lower Mississippi River	M/V Galini	Freight Ship	No. 6 Fuel	3,190
9/10/95	Violet	LA	Lower Mississippi River	Golden Eagle	Freight Ship	No. 6 Fuel	3,350
9/28/95	Tampa	FL	Tampa Bay	Unknown Vessel	Unclassified Vessel	No. 6 Fuel	5,000
10/2/95	Everett	WA	Puget Sound	Mobile Oil Inc	Land Facility	No. 6 Fuel	27,000
10/25/95	Bayonne	NJ	Kill Van Kull	IMTT Bayonne	Facility	No. 6 Fuel	23,000
11/27/95	Manhattan	NY	East River	Con-Ed Generating Station	Waterfront Facility	No. 6 Fuel	5,200
12/12/95	Bayamon	PR	N Atlantic Ocean Coastal	Hospital De Bayamon	Facility	No. 5 Fuel	2,500
1/27/96	Staunton	IL	Sugar Camp Creek	Staunton Fuel Inc	Vehicle	No. 5 Fuel	2,000
2/16/96	Saint Paul	AK	Bering Sea	Citrus	Freight Ship	No. 6 Fuel	500
2/24/96	Corpus Christi	TX	Corpus Christi Ship Channel	Coastal Marketing & Refining	Transfer	No. 6 Fuel	1,460
3/7/96		AL	Black Warrior River		Facility	Heavy Fuel	1,400
3/14/96	Corpus Christi	TX	Corpus Christi Ship Channel	Coastal 2532-L	Tank Barge	No. 6 Fuel	5,250
3/18/96		TX	Houston Ship Channel	Buffalo 292	Tank Barge	No. 6 Fuel	176,400
5/14/96	Oahu Island	HI	Pearl Harbor	Chevron Pipeline	Pipeline	No. 6 Fuel	41,000
5/26/96	Houston	TX	Houston Ship Channel	Buffalo 286	Tank Barge	No. 6 Fuel	25,998

Table A-1. Heavy oil spills of at least 500 gallons into U.S. navigable waters 1995-2004[1] (Continued).

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
6/21/96	Myrtle Grove	LA	Lower Mississippi River	MF 12	Tank Barge	No. 6 Fuel	3,534
9/8/96			Galveston Bay	Havglimt	Tank Ship	No. 6 Fuel	8,030
9/19/96	Chickasaw	AL	Navigable Waters	Babuyan	Freight Ship	No. 6 Fuel	2,000
10/17/96	Lewiston	ME	Androscoggin River	Pepperel And Associates	Facility	No. 6 Fuel	500
10/27/96	Los Angeles	CA	Port Los Angeles/Long Beach	Orenoco Reefer	Freight Ship	No. 5 Fuel	1,835
11/15/96	New York	NY	East River	Con-Ed Generating Station	Waterfront Facility	No. 6 Fuel	3,000
2/25/97	Ft Lauderdale	FL	Navigable Waters	Port Everglades	Waterfront Facility	No. 6 Fuel	2,600
2/25/97	Bayonne	NJ	New York Harbor Upper Bay	Bitlis	Freight Ship	No. 6 Fuel	3,500
3/19/97	Pago Pago	AS	South Pacific Ocean Coastal	Melone	Freight Ship	No. 6 Fuel	600
3/22/97		AS	South Pacific Ocean Coastal	Melone	Freight Ship	No. 6 Fuel	600
5/11/97	N Kingstown	RI	Narragansett Bay	RI Economic Development	Facility	No. 6 Fuel	800
5/15/97	Carteret	NJ	Arthur Kill	RTC No. 320	Tank Barge	No. 6 Fuel	52,000
6/20/97	Long Beach	CA	Port Los Angeles/Long Beach	Moana Pacific	Freight Ship	No. 5 Fuel	1,680
8/6/97	Ferndale	WA	Puget Sound	Tosco Refinery	Facility	No. 6 Fuel	16,800
11/5/97	Samoa	CA	N Pacific Ocean Coastal	Kure	Freight Ship	No. 5 Fuel	4,537
11/26/97	Unalaska	AK	Bering Sea	Kuroshima	Freight Ship	No. 6 Fuel	47,000
12/21/97	Catlettsburg	KY	Big Sandy River	AO 802	Barge	No. 5 Fuel	46,000
3/27/98	Middletown	CT	Connecticut River	Connecticut Valley Hospital	Facility	No. 6 Fuel	1,000
5/9/98	Linden	NJ	Arthur Kill	Wilma Yangtze	Tank Ship	No. 6 Fuel	600
6/24/98	Mobile	AL	Mobile River	USS Alabama	Unclassified Vess.	No. 5 Fuel	4,800
6/25/98	West Warwick	RI	Pawtucket River	Crompton Grain Company Inc	Facility	No. 6 Fuel	5,000
6/30/98	Honolulu	HI	Honolulu Harbor	State Of Hawaii DLNR	Facility	No. 5 Fuel	900
8/24/98	Honolulu	HI	N Pacific Ocean Coastal	Tesoro Hawaii Corp (SPM)	Waterfront Facility	No. 6 Fuel	4,914
9/15/98	None	NA	Navigable Waters	Mare Princess	Tank Ship	No. 6 Fuel	2,520
9/21/98	San Juan	PR	Caribbean Sea	Caribbean Petroleum Refining	Facility	No. 6 Fuel	16,800
9/27/98	Half Moon Bay	CA	N Pacific Ocean Coastal	Command	Tank Ship	No. 6 Fuel	30,000
9/28/98	Off San Francisco	CA	Pacific Ocean	Command	Tanker	No. 6 Fuel	51,450
10/14/98	Delaware City	DE	Delaware River	New Ideal	Tank Ship	No. 6 Fuel	2,300
10/26/98	Camden	NJ	Delaware River	Del Monte Consumer	Freight Ship	No. 6 Fuel	3,710
11/16/98	Honolulu	HI	N Pacific Ocean Coastal	Holo Kai	Tank Barge	No. 6 Fuel	2,352
11/27/98	Los Angeles	CA	Port Los Angeles/Long Beach	W.T. 25	Tank Barge	No. 5 Fuel	2,142
12/24/98	Charlestown	MA	Boston Harbor	Boston Edison Company	Land Fac/Non Marine	No. 6 Fuel	80,000
1/9/99	Pago Pago	AS	N Pacific Ocean Coastal	Unknown Vessel	Unclassified Vess.	No. 6 Fuel	1,050
1/13/99	Off Charleston	SC	Atlantic Ocean	Star Evviva	Other Vessel	No. 6 Fuel	24,000
2/14/99	Far Hills	NJ	N Branch Raritan River		Facility	No. 6 Fuel	2,000

Table A-1. Heavy oil spills of at least 500 gallons into U.S. navigable waters 1995-2004[1] (Continued).

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
3/4/99	Long Beach	CA	Port Los Angeles/Long Beach	Olympic L	Tank Barge	No. 6 Fuel	6,890
3/6/99	Port Allen	LA	Lower Mississippi River	Apex 3508	Tank Barge	No. 6 Fuel	3,970
3/14/99	Galveston	TX	Galveston Bay	Galveston Terminals Inc.	Waterfront Facility	No. 5 Fuel	3,780
5/13/99	Rosarito	CA	San Diego Harbor	Pemex Refinacion	Refining	No. 6 Fuel	60,000
6/19/99	Virginia Beach	VA	N Atlantic Ocean Coastal	Unknown Land Source	Shoreline Facility	No. 6 Fuel	1,200
7/31/99	Long Beach	CA	Port Los Angeles/Long Beach	Zim Israel	Freight Ship	No. 6 Fuel	900
8/12/99	New Orleans	LA	Lower Mississippi River	S.S. Unoin Faith	Unclassified Vess.	No. 6 Fuel	1,000
8/27/99	Galveston		Gulf Of Mexico	Blue Master	Freight Ship	No. 6 Fuel	18,900
9/6/99	Eureka	CA	N Pacific Ocean Coastal	Stuyvesant	Industrial Vessel	No. 5 Fuel	2,100
9/19/99	Brooklyn	NY	New York Harbor Lower Bay	Jonas Equities	Other	No. 6 Fuel	2,300
10/21/99	Jacksonville	FL	St. Johns River	Hmi Diamond Shoals	Tank Ship	No. 6 Fuel	1,000
11/8/99	Catlettsburg	KY	Big Sandy River	Marathon Ashland Petroleum	Facility	No. 5 Fuel	688,230
5/2/00	Corpus Christi	TX	Corpus Christi Ship Channel	Moc V	Tank Barge	No. 6 Fuel	2,420
5/31/00	Woonsocket	RI	Blackstone River		Facility	No. 6 Fuel	4,000
6/6/00	Brooklyn	NY	New York Harbor Upper Bay	Brooklyn Army Terminal	Municipal Facility	No. 6 Fuel	5,000
6/8/00	Boston	MA	Atlantic Ocean	Tosco Terminal	Vehicle	No. 6 Fuel	59,000
6/12/00	Baytown	TX	Houston Ship Channel	HMS 111	Tank Barge	No. 6 Fuel	70,130
7/5/00	Newport	RI	Narragansett Bay	Penn No. 460	Tank Barge	No. 6 Fuel	14,000
7/13/00	Ingleside	TX	Intracoastal Waterway-Gulf	Hollywood 213	Tank Barge	No. 6 Fuel	7,476
7/31/00	Pitusville	FL	Indian River		Facility	No. 6 Fuel	500
8/17/00	Charlestown	MA	Mystic River	Sithe Mystic Station	Facility	No. 6 Fuel	500
9/29/00	Philadelphia	PA	Schuylkill River	Sunoco Inc	Pipeline	No. 6 Fuel	14,700
10/5/00	Chesapeake	VA	Elizabeth River	VB40	Tank Barge	No. 6 Fuel	4,200
11/20/00	Belle Chase	LA	Lower Mississippi River	CT 2629	Tank Barge	No. 6 Fuel	2,000
12/16/00	Weirton	WV	Ohio River	Weirton Steel Facility	Facility	No. 6 Fuel	3,000
3/20/01	New Haven	CT	Long Island Sound	Rhode Island	Tank Barge	No. 6 Fuel	12,600
3/27/01	Queens	NY	Long Island Sound	Bay Terrace Coop. Inc.	Land Facility	No. 6 Fuel	600
4/20/01	Piti	GU	Navigable Waters	Shell Petroleum	Waterfront Facility	No. 6 Fuel	520
6/27/01	Wellsville	OH	Ohio River	Marathon Ashland Petroleum	Waterfront Facility	No. 6 Fuel	850
7/16/01	Miami	FL	N Atlantic Ocean Coastal	Argentinean Reefer	Freight Ship	No. 6 Fuel	500
9/22/01	Baltimore	MD	Patapsco River	Unknown Vessel	Unclassified Vessel	No. 6 Fuel	500
11/7/01	Hicksville	NY	Long Island Sound	Keyspan Steam Station	Waterfront Facility	No. 6 Fuel	1,000
11/29/01	Camas	WA	Columbia Slough		Facility	No. 6 Fuel	500
12/18/01	Philadelphia	PA	Schuylkill River		Facility	No. 6 Fuel	2,000

Table A-1. Heavy oil spills of at least 500 gallons into U.S. navigable waters 1995-2004[1] (Continued).

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
1/28/02	Barlow Point	AK	Pacific Ocean	Pendrecht	Freight Ship	No. 6 Fuel	1,000
3/21/02		NJ	Atlantic Ocean	B. No. 195	Tank Barge	No. 6 Fuel	1,500
5/19/02	Port Angeles	WA	Puget Sound	Gaz Diamond	Tank Ship	No. 6 Fuel	512
9/30/02		SC	Cooper River	Ever Reach	Container Ship	No. 6 Fuel	12,500
12/5/02	Corpus Christi	TX	Corpus Christi Bay	Moc IV	Tank Barge	No. 6 Fuel	10,500
12/7/02		AL	Mobile River	Lorelay	Pipe Laying	No. 6 Fuel	3,696
3/1/03	Corpus Christi	TX	Corpus Christi Bay	Emerald Star	Tank Ship	No. 6 Fuel	714
4/1/03		MA	Buzzards Bay	Bouchard No. 120	Tank Barge	No. 6 Fuel	98,000
8/21/03	Pittsburg	CA	Willow Creek	Mirant	Facility	No. 6 Fuel	4,200
10/4/03			Lake Superior	Presque Isle	Towing Vessel	No. 6 Fuel	1,100
12/30/03		WA	Puget Sound	Foss 248 P2	Tank Barge	No. 6 Fuel	4,800
3/23/04		NC	Catawba River	Old Ford Finishing	Fixed	No. 6 Fuel	1,000
7/28/04	Honolulu	HI	Pacific Ocean Keehi Lagoon		Barge	No. 6 Fuel	700
10/14/2004	Dalco Passage	WA	Puget Sound	Polar Texas	Tanker	Heavy Fuel	1,500
11/26/04		PA	Delaware River	Athos I	Tanker	Heavy Crude	265,000

Table Notes:

(1) Source: Proprietary database of oil spill statistics maintained and updated by Environmental Research Consulting, Cortlandt, NY.

T/V ARCO ANCHORAGE

12/21/1985: 189,000 gallons of Alaskan crude, Port Angeles, WA.

This spill involved crude oil. The spill entered the Straits of Juan de Fuca. There was a significant cleanup effort. The NRD costs and cleanup costs associated with the spill were well documented. ASA has the current data for modeling spill trajectories in the Straits of Juan de Fuca. However, the spill was some time ago, and personnel involved in the response may be difficult to contact.

T/B BOUCHARD 155 (Tampa Bay)

8/10/1993: 330,000 gallons of No. 6 fuel (submerged oil), Tampa Bay, FL.

This involved a significant amount of No. 6 oil that did sink. The oil initially moved out to sea and then came ashore on the coast north of St. Petersburg when the winds shifted. Detection of the oil on the bottom was an issue in the ensuing cleanup effort that included submerged oil recovery. Oil detection was accomplished by divers and bottom sampling. ASA did the NRDA modeling for the spill and has the current data for trajectory modeling. The response was well documented in terms of response actions and cleanup costs. This spill may be a good spill to start out with on the cost-benefit modeling effort as the LF would probably have had an impact and analysis can begin immediately.

T/B BUFFALO 286 and T/B BUFFALO 292

5/26/1996: 42,000 gallons of No. 6 fuel, Galveston Bay, TX.

3/18/1996: 189,000 gallons of IFO, Galveston Bay, TX.

Both the T/B Buffalo 286 and T/B Buffalo 292 spills occurred in Galveston Bay due to structural failure of the barge and grounding. Both spills required some cleanup operations and some cost data are available. The spill was largely confined to Galveston Bay. ASA did not model these spills but has the current information to support trajectory modeling.

T/V PUERTO RICAN

10/31/1984: 4.2 million gallons, Bodega Bay, off San Francisco, CA.

This is an older spill but did involve a significant cleanup effort and cleanup costs. The spill involved several types of oil and chemicals including heavy fuel oil. Much of the oil either burned or sank offshore (1.17M gallons burned and 336,000 gallons sank). ERC has the cost data for the spill. The currents in the area are complicated but ASA does have a simulation. It is not clear how the LF might have figured into the spill response effort. Response personnel may be difficult to interview because the spill occurred so long ago.

T/V POLAR TEXAS (Dalco Passage Spill)

10/14/2004: 1,000-1,500 gallons of oil (type TBD), Dalco Passage, Puget Sound, WA.

This is a more recent spill. There was initial uncertainty on the source of the spill and difficulty in determining the extent of the spill at night. ASA has not yet modeled the spill but does have the currents. This spill is a possibility for the cost-benefit modeling effort if the cost data can be made available. However, the amount of oil spilled was moderate which may decrease the importance of the LF contribution had it been available.

T/V ATHOS I

11/26/2004: 265,000 gallons of heavy crude, Delaware River.

This is an ongoing spill cleanup effort involving heavy oil that sank. Detection of the submerged oil is an important issue. There is a need to check on the availability of cleanup cost data pending any ongoing litigation. (This would be simplified if the spill costs were being covered by the Oil Spill Liability Trust Fund.) If cost data are not immediately available, they could be estimated based on equipment usage. ASA has current data to support trajectory modeling. This spill is a good candidate if cost data can be compiled to support modeling.

M/V KURE

11/5/1997: 5,000 gallons of Bunker C fuel, Humboldt Bay, CA.

ASA did the NRDA work for this spill. There was damage to the marshes in Humboldt Bay. This was a very expensive spill cleanup effort on a cost per gallon basis. However, it is not clear how much oil was in the marsh and whether more quickly locating the oil would have significantly reduced cleanup costs.

PEPCO PIPELINE

4/7/2000: 138,600 gallons of No. 6/No. 2 fuels, Patuxent River, Chalk Point, MD.

This is potentially a good candidate for assessing LF detection impact on cleanup efforts on a marshy coast. Detection was an issue: responders did not initially know the full extent of oiling in the marsh. Significant amounts of oil also migrated out of the marsh. Cleanup costs are heavily documented, but the spill is still in litigation. Need to check on availability of cost data.

T/B NESTUCCA

12/23/1988: 253,000 of gallons of No. 6 fuel oil.

Oil dispersed over wide area. Heavy sea impeded immediate containment and cleanup. Oil was difficult to locate. NRDA and cleanup cost data are available. ASA will have the current data to support trajectory modeling by end of November. Good potential historical spill candidate for LF cost-benefit modeling. The primary drawback is the date of the spill (15 years ago) and the difficulty in contacting response personnel.

T/B BOUCHARD No. 120 Spill in Buzzards Bay

4/27/2003: 98,000 gallons of No. 6 fuel oil, Buzzards Bay.

ASA is modeling the spill. However, NOAA legal office has determined that the cost data cannot be released. Data will probably not be available in time to use in LF cost-benefit modeling.

APPENDIX B.

RESULTS AND UNCERTAINTIES ASSOCIATED WITH THE SCENARIO-BASED COST-SAVINGS ANALYSIS

This appendix provides supplemental results for the scenario-based savings analysis generated by the SIMAP Model. These additional results include:

- a plot of oil removal rates under different response options with ten percent enhancement of recovery with the LF;
- a comparison of oil coming ashore and oil recovered for the different LF implementation scenarios;
- plots of mass balance over time broken down for each environmental compartment where the oil resides; and,
- a summary table of mass balance for the different LF implementation scenarios considered.

Tables and graphs are provided for each of the spills simulated using the SIMAP model: the T/B BOUCHARD 155 spill, the T/V COMMAND spill, the PEPCO spill and the hypothetical spill in the Strait of Juan de Fuca.

This appendix also provides a discussion of the general assumptions and uncertainties involved in estimating mass balance and cost savings for these spills using the SIMAP model.

Oil Ashore Versus Oil Recovered and Mass Balance Results

Results for the T/B BOUCHARD 155 Spill in Tampa Bay

Figure B-1 and Table B-1 show the percentage of oil recovered for the T/B BOUCHARD spill under different LF implementation scenarios. The data show that there is an advantage with the LF with regard to increasing oil removal particularly if oil removal is enhanced by at least ten percent with the LF, as shown in Figure B-1 and Table B-1.

Some of the (small) variations seen in Table B-1 are attributable to random “noise” rather than to significant differences in oil removal or shoreline oiling (for example, F72A versus F72B). This noise is attributed to the random variability (due to turbulence) that results in variation in the specific water areas and shoreline locations oiled. This randomization causes some degree of variation in the results that may be greater than the trend induced by changes in assumed spill response. (See discussion on page B-12).

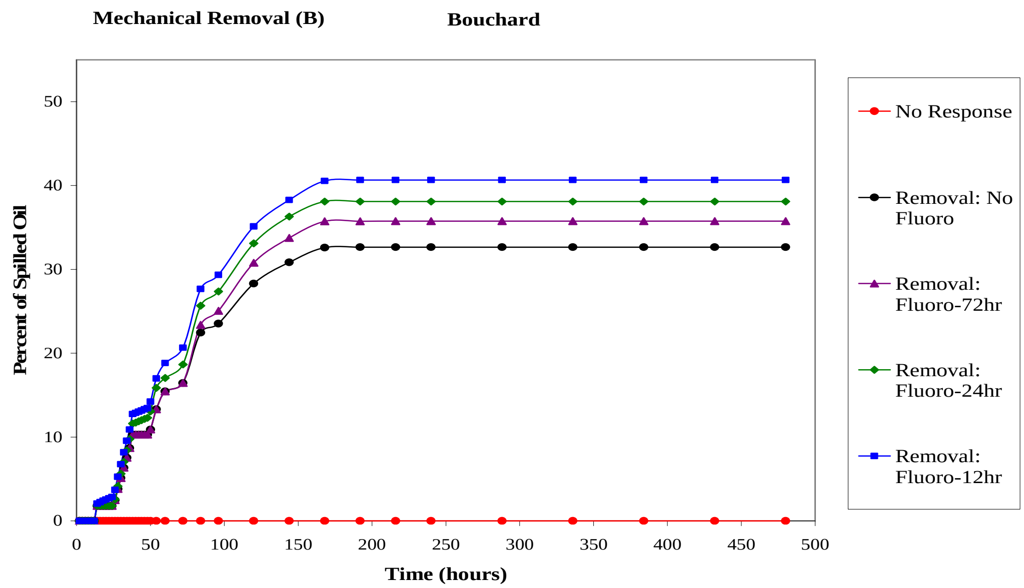

Figure B-1. Oil removal rates under different responses for the T/B BOUCHARD 155 spill with 10 percent enhancement of recovery with the LF.

Table B-1. Comparison of alternate spill responses: T/B BOUCHARD 155 spill.

Scenario	% Ashore	% Difference from NF	Oil Recovered (gallons)	% Difference from NF
NF	34.1	0.0	107,754	0
F12A	33.1	-3.0	121,562	13
F12B	32.4	-5.2	134,170	25
F12C	31.2	-8.6	138,904	29
F12D	26.2	-23.4	169,723	58
F24A	32.8	-4.0	119,329	11
F24B	32.3	-5.5	125,734	17
F24C	31.0	-9.3	140,477	30
F24D	28.2	-17.4	161,678	50
F72A	33.3	-2.5	114,998	7
F72B	33.4	-2.3	118,003	10
F72C	32.2	-5.8	123,337	14
F72D	31.1	-9.0	138,646	29

The recovery parameters and their abbreviations:

No fluorosensor (NF): the actual response or theoretical response is conducted without the benefit of LF, including cessation of oil removal operations during darkness.

F2 (or F12): the actual response is enhanced by the use of LF at 2 or 12 hours. Oil recovery is enhanced during daylight hours after 2 or 12 hours. Nighttime removal operations are

possible once the LF and removal equipment are both on-scene, albeit at a rate much reduced from daylight operations.

F24: the actual response enhanced by the use of LF at 24 hours. Oil recovery is enhanced during daylight hours after 24 hours. Nighttime removal operations are possible after 24 hours, albeit at a rate much reduced from daylight operations.

F72: the actual response enhanced by use of LF at 72 hours. Oil recovery is enhanced during daylight hours after 72 hours. Nighttime removal operations are possible after 72 hours, albeit at a rate much reduced from daylight operations.

Enhanced removal effectiveness options are:

A: 5 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

B: 10 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

C: 20 percent increase over actual oil recovery during day; 10 percent of day recovery at night;

D: 40 percent increase over actual oil recovery during day; 20 percent of day recovery at night.

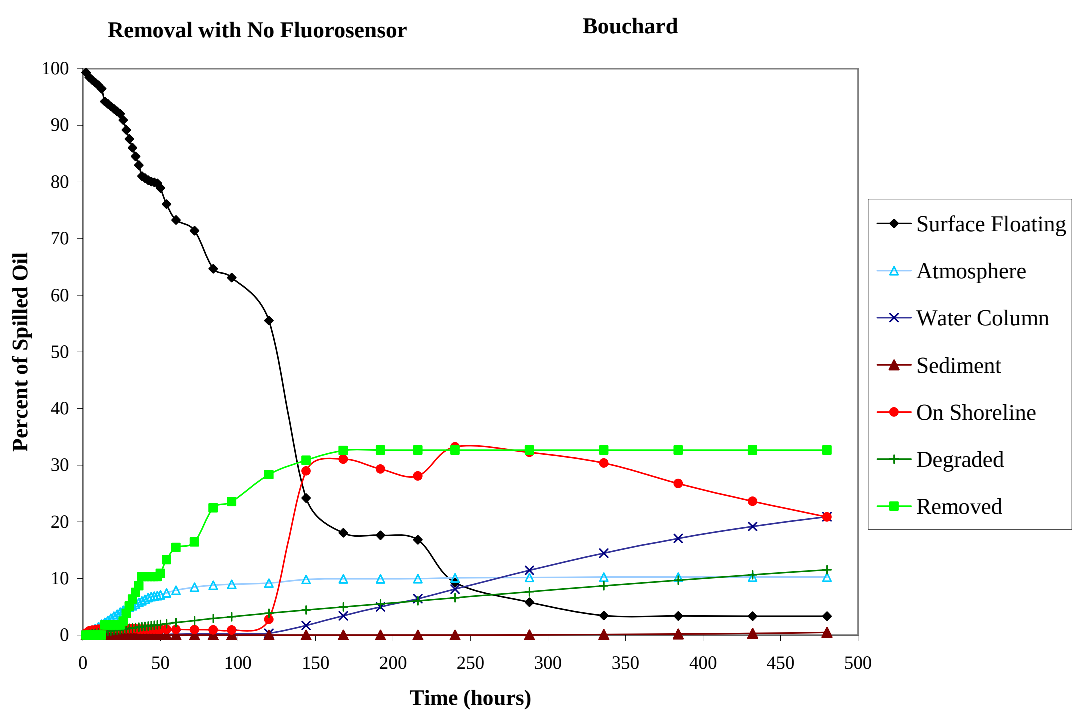

Figure B-2. Mass balance under the NF scenario for the T/B BOUCHARD 155 spill.

Table B-2. Mass balance for alternate spill responses: T/B BOUCHARD 155 spill.

Scenario	Evaporated (%)[1]	Water Column (%)[1]	Sediment (%)[1]	Shoreline (%)[1]	Degraded (%)[1]	Removed (%)[1]
NF	10	22	1	34	12	33
F12A	10	21	1	33	11	37
F12B	10	20	1	32	11	41
F12C	10	20	1	31	11	42
F12D	9	16	0	26	9	51
F24A	10	21	1	33	11	36
F24B	10	21	1	32	11	38
F24C	10	20	1	31	10	43
F24D	10	17	1	28	9	49
F72A	10	21	1	33	12	35
F72B	10	21	1	33	12	36
F72C	10	20	1	32	11	37
F72D	10	19	1	31	11	42

Table Notes:

(1) The “mass balance” represents the *maximum* percentage in each of these categories and is not intended to be added together to equal 100 percent. There is some shifting from one column to another. For example, oil on the shoreline can re-enter the water column. The degraded percentage is a *subset* of the shoreline percentage in that some of the oil on the shoreline actually begins to break down after time. This can be seen in Figure B-2, where the shoreline oil, represented in red, actually reduces after 250 hours. Some of that oil is degrading and some of that oil is also entering the water column. Some of the oil that is in the water column entered directly from the surface slick. Oil in the water column can then end up in the sediment. There is also some “rounding error” that occurs, as well as a small percentage (perhaps as much as 3 percent) that is “out of bounds” in the model. This is an artifact of the model in that a small percentage of the “spillets” (oil “particles” in the model) randomly moves outside the area of the modeling map.

Results for the T/V COMMAND Spill of San Francisco

Figure B-3 and Table B-3 show the results for the percentage of oil recovered for the T/V COMMAND spill with and without the LF under different LF implementation scenarios.

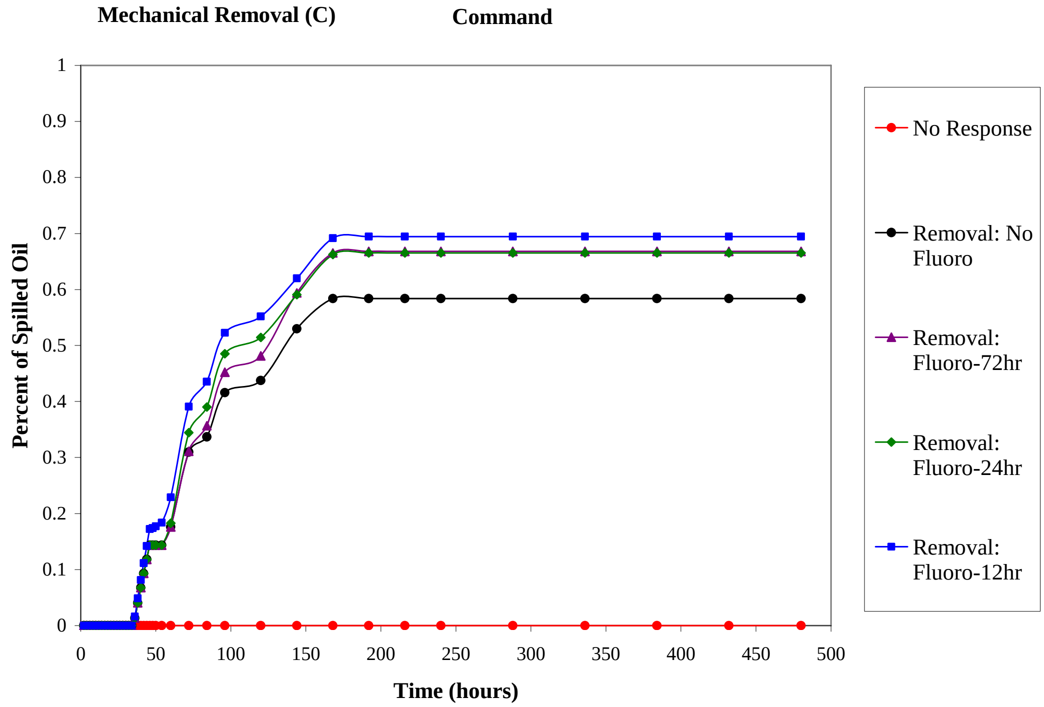

Figure B-3. Oil removal rates under different responses for the T/V COMMAND spill with 10 percent enhancement of recovery with the LF.

Table B-3. Comparison of alternate spill responses: T/V COMMAND spill.

Scenario	% Ashore	% Difference from NF	Oil Recovered (gallons)	% Difference from NF
NF	73.2	0.0	18	0.0
F12A	73.1	0.0	20	0.0
F12B	73.1	-0.1	20	-0.1
F12C	73.4	0.4	22	0.4
F12D	73.3	0.1	26	0.1
F24A	73.2	0.0	19	0.0
F24B	73.1	0.0	20	0.0
F24C	73.1	0.9	20	0.9
F24D	73.1	-0.2	24	-0.2
F72A	73.2	0.0	18	0.0
F72B	73.2	1.0	18	0.0
F72C	73.2	0.0	19	0.0
F72D	73.1	-0.1	20	-0.1

There appears to be no significant difference between oil removal amounts with the use of the LF. Small differences seen in the data are mostly attributable to random "noise," rather than to actual differences in impacts (refer to page B-12 for details). Oil recovery rates are very low because the oil spread out and formed tar balls by the time recovery operations got underway. With earlier notification and the initiation of spill response operations 12 or 24 hours earlier, higher rates of oil recovery would likely have been achieved.

The mass balance of the oil spilled from the T/V COMMAND spill is shown in Figure B-4 and Table B-4. There is very little difference in NRD with the use of the LF in this spill. This is mainly due to the fact that there is relatively little increase in oil removal with the use of the LF because of the spread of the oil at the late time at which the LF would be deployed.

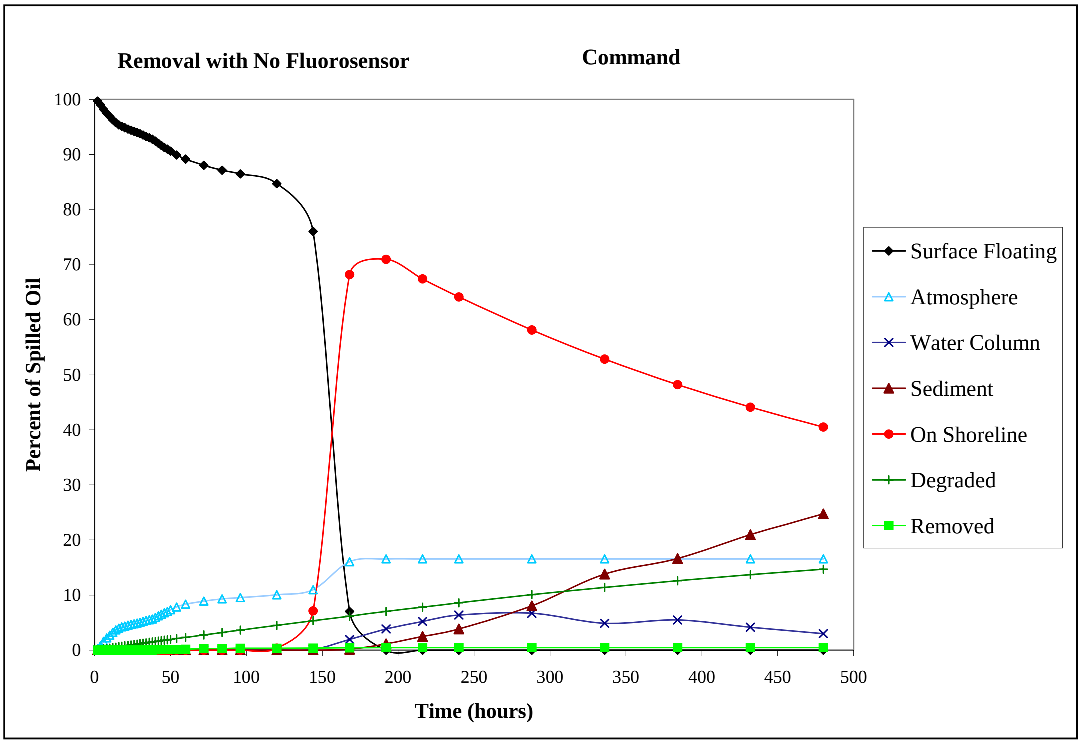

Figure B-4. Mass balance of oil under the NF response scenario for the T/V COMMAND spill.

Table B-4. Mass balance for alternate spill responses: T/V COMMAND spill.

Scenario	Evaporated (%)	Water Column (%)	Sediment (%)	Shoreline (%)	Degraded (%)	Removed (%)
NF	17	8	28	73	15	1
F12A	17	8	28	73	15	1
F12B	17	8	28	73	15	1
F12C	17	7	25	73	15	1
F12D	17	8	28	73	15	1
F24A	17	8	28	73	15	1
F24B	17	8	28	73	15	1
F24C	17	8	28	74	15	1
F24D	17	7	26	73	15	1
F72A	17	8	28	73	15	1
F72B	17	8	29	74	15	0
F72C	17	8	28	73	15	1
F72D	17	8	28	73	15	1

Results for the PEPCO Pipeline Spill on the Patuxent River, MD

The differences in oil removal (recovery) rates and shoreline impacts for the PEPCO spill with and without the LF for this spill are shown in Figure B-5 and Table B-5. The results show that the amount of oil recovered is higher if the LF is implemented sooner (at 2 hours or 24 hours) rather than at 72 hours. However, the differences between the rates assumed in A, B, C and D produce results that are smaller than the random variability in the model. There is somewhat more variability in the amount of oil coming ashore than in the volume of oil recovered, because the randomization component in the model transport algorithm brings oil closer or farther from shorelines, inducing variability in whether a particular shoreline is hit. There is no measurable difference between the 72-hour and the NF results (that is, differences are less than the variability in the model). There are small differences between the 2-hour and the 24-hour results.

Thus, for this spill, there is clearly an advantage in having the LF for the response in that more oil is removed, though that advantage is only realized with its use within 24 hours. At 72 hours, the oil has sufficiently spread so that there would be virtually no difference between the NF and LF scenarios.

The mass balance of the oil spilled from the PEPCO Pipeline spill is shown in Figure B-6 and Table B-6.

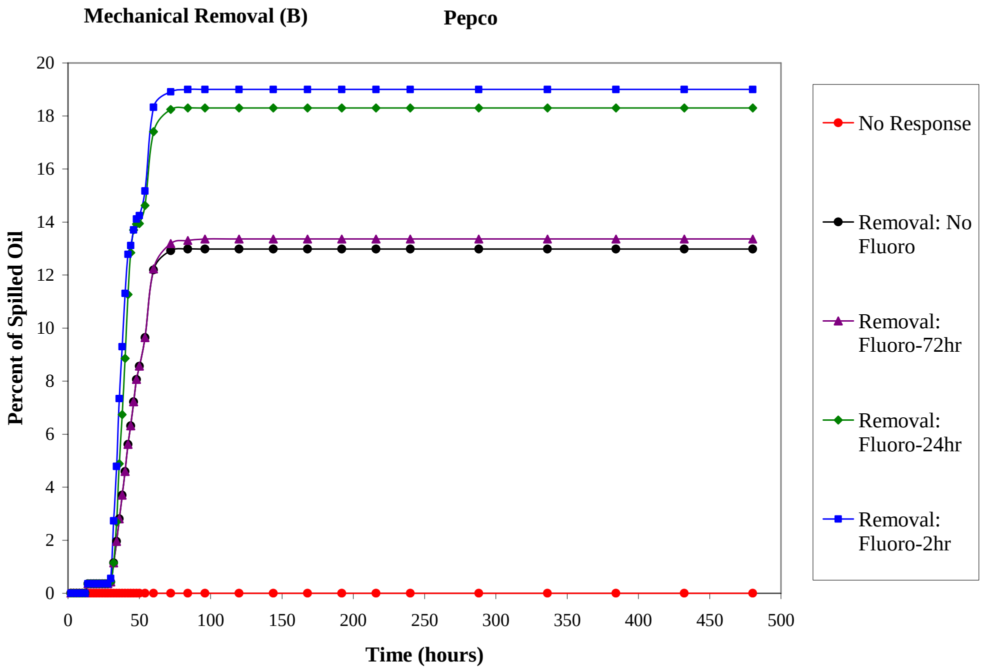

Figure B-5. Oil removal rates with different responses for the PEPCO spill with 10 percent enhancement of recovery with the LF.

Table B-5. Comparison of alternate spill responses: PEPCO pipeline.

Scenario	% Ashore	% Difference from NF	Oil Recovered (gallons)	% Difference from NF
NF	19.8	0.0	17,991	0.0
F2A	18.6	-5.9	26,940	49.7
F2B	18.6	-6.2	26,332	46.4
F2C	18.7	-5.5	26,375	46.6
F2D	18.6	-6.2	26,415	46.8
F24A	18.7	-5.7	25,357	40.9
F24B	18.8	-5.0	25,357	40.9
F24C	19.0	-3.9	25,363	41.0
F24D	18.7	-5.7	25,246	40.3
F72A	19.5	-1.2	17,867	-0.7
F72B	19.9	0.5	18,515	2.9
F72C	19.9	0.7	17,910	-0.4
F72D	19.4	-2.2	17,941	-0.3

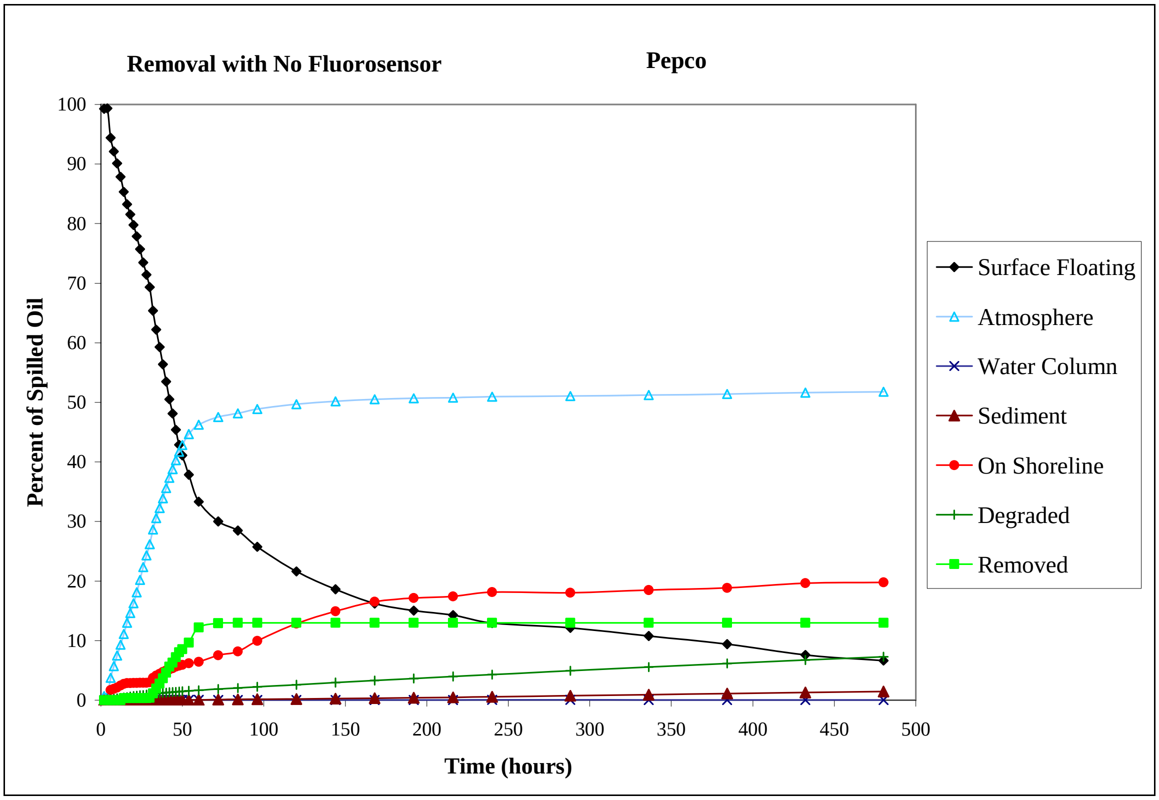

Figure B-6. Mass balance for PEPCO pipeline spill under the NF response scenario.

Table B-6. Mass balance for alternate spill responses: PEPCO pipeline spill.

Scenario	% Evaporated	% Water Column	% Sediment	% Shoreline	% Degraded	% Removed
NF	52	0	2	20	8	13
F2A	50	0	2	19	7	19
F2B	50	0	2	19	7	19
F2C	50	0	1	19	7	19
F2D	50	0	1	19	7	19
F24A	50	1	2	19	7	18
F24B	50	1	2	19	7	18
F24C	50	0	1	19	7	18
F24D	50	1	2	19	7	18
F72A	52	0	2	20	8	13
F72B	52	0	2	20	7	13
F72C	52	0	2	20	8	13
F72D	52	1	2	19	8	13

Results for the Hypothetical Oil Spill in the Strait of Juan de Fuca

The differences in oil removal (recovery) rates and shoreline impacts with and without the LF are shown in Figure B-7 and Table B-7. For this spill case, which is in a high-energy environment with strong currents, the model transport includes a large amount of random variability (due to turbulence) that results in variation in the specific water areas and shoreline locations oiled. This randomization causes some degree of variation in the results that may be greater than the trend induced by changes in assumed spill response. (See discussion on page B-B-12). This induces some "noise" in the results. That noise is a measure of uncertainty. Thus, the differences between alternative response scenario results are in the same order of magnitude as the natural variability in the environment reflected in the variability in the model runs.

Even considering the variability and uncertainty of the trajectory for this spill, which involves a much larger volume of oil than the other spills analyzed, there appears to be an advantage in employing the LF, as evidenced particularly by the results for F12D, F24D, and F72D compared to NF. Shoreline oiling is reduced and more oil is recovered offshore than when the LF is not employed (the NF scenario).

The mass balance of oil for this spill is shown in Figure B-8 and Table B-8.

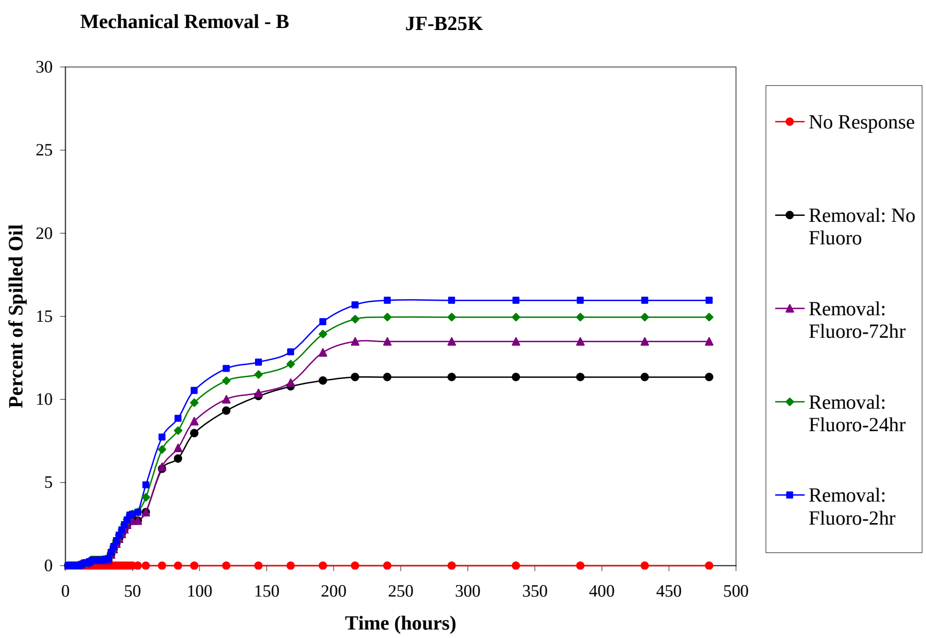

Figure B-7. Oil removal rates under different response scenarios for the Strait of Juan de Fuca spill with 10 percent enhancement of recovery with the LF.

Table B-7. Comparison of alternate spill responses: Strait of Juan de Fuca spill.

Scenario	% Ashore	% Difference from NF	Oil Recovered (gallons)	% Difference from NF
NF	55.1	0.0	119,094	0.0
F12A	55.1	0.0	152,972	28.4
F12B	54.5	-1.2	167,671	40.8
F12C	55.5	0.7	162,115	36.1
F12D	53.0	-3.8	255,610	114.6
F24A	55.3	0.4	157,847	32.5
F24B	54.4	-1.2	156,990	31.8
F24C	54.5	-1.1	178,896	50.2
F24D	50.4	-8.6	283,578	138.1
F72A	56.6	2.6	138,584	16.4
F72B	59.7	8.2	141,614	18.9
F72C	55.1	0.0	141,822	19.1
F72D	52.8	-4.1	217,152	82.3

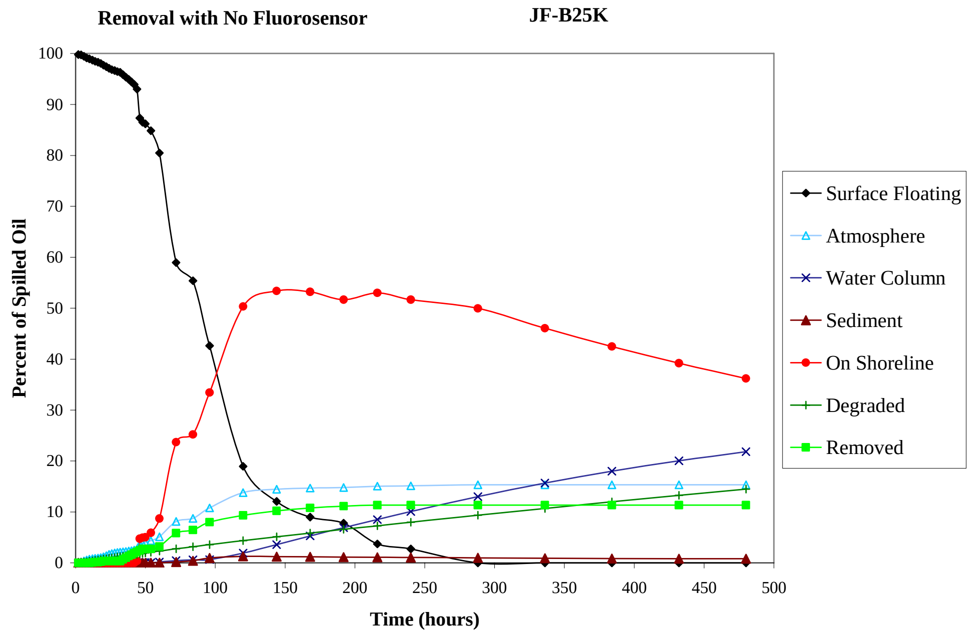

Figure B-8. Mass balance for Strait of Juan de Fuca spill under NF response scenario.

Table B-8. Mass balance for alternate spill responses: Strait of Juan de Fuca spill.

Scenario	Evaporated (%)	Water Column (%)	Sediment (%)	Shoreline (%)	Degraded (%)	Removed (%)
NF	15	30	2	55	32	11
F2A	15	29	2	55	31	15
F2B	15	28	1	54	30	16
F2C	15	29	2	56	31	15
F2D	14	25	1	53	27	24
F24A	15	21	1	55	15	15
F24B	15	29	2	54	31	15
F24C	15	21	1	55	14	17
F24D	13	25	1	50	26	27
F72A	15	29	1	57	32	13
F72B	15	29	1	60	31	13
F72C	15	30	1	55	31	14
F72D	14	27	2	53	29	21

Uncertainties in Cost Computations and Assumptions for the Scenario-Based Cost-Savings Analysis

Estimating the response, NRDA, and socioeconomic costs associated with hypothetical spills, such as the alternate responses using the LF technology, requires an understanding of the ways in which costs might be influenced by changes in the behavior, fate, and effects of the oil. The SIMAP modeling used in this study provides detailed information on these factors but does not directly estimate how these changes might influence the various cost categories. Extrapolating from the data outputs from SIMAP to costs is a complex process and one that requires major assumptions. The process inevitably will have inaccuracies.

Response Cost Calculations

Spill response costs are generally an aggregate of the costs to conduct a variety of operations in a spill response, including:

- Mobilization;
- Protective booming;
- Mechanical containment and recovery operations;
- Spill management;
- Spill monitoring by government officials;
- Salvage (source control and stabilization);
- Shoreline cleanup;
- Decontamination of equipment and worker clothing/gear;
- Wildlife rescue and rehabilitation;
- Disposal of collected oil and debris.

There are a number of methods that can be used to estimate response costs for hypothetical spill scenarios. Estimating response costs for hypothetical oil spill scenarios should rely heavily on patterns and data from previous oil spill cases. Since the number of moderate-to larger-oil spills has decreased in recent years (Etkin, 2001a and 2003), there are fewer spills on which to base oil spill response cost models. Rather than relying exclusively on costs derived from past spills, it is also possible to enhance cost estimates by studying costs for resource and personnel allocations for hypothetical scenarios in area contingency plans and exercises. This also allows for oil spill costs to be estimated for hypothetical spills that are unlike other spills that have occurred in the past. A combination of actual and modeled hypothetical spill response costs has been employed in various studies (Etkin, 2001a, 2001b, and 2004; Etkin et al., 2002 and 2003; Etkin and Tebeau, 2003; French-McCay et al., 2004) to estimate costs for hypothetical spills. This methodology is employed in estimating the costs for the hypothetical Strait of Juan de Fuca spill for which no actual data are available since there was no actual spill.

The question of “accuracy” for oil spill cost estimates arises when modeling hypothetical responses to hypothetical spill scenarios. It is virtually impossible to accurately predict the cost of any spill response because there are too many unknown factors. The actual efficacy of spill response equipment and work crews, weather and other factors that can influence response progress, and the possibility of strategic or judgmental errors on the part of response officials or spill managers, are all difficult to predict.

Another important set of factors that can influence costs, but that are also difficult to foresee, are contractual problems, irregularities, errors, or even improprieties on the part of spill response contractors and spill management teams. There can be tremendous differences in the rates that spill response contractors charge to clients (responsible parties) that already have contractual agreements and those that do not. In addition, there are different governmental and commercial rates that come into play depending on whether the contractors are hired directly by the responsible party or by government officials, who will then later seek reimbursement to the Oil Spill Liability Trust Fund from the responsible party.

For the scenarios in which an actual spill with actual reported costs (T/B BOUCHARD 155, T/V COMMAND, and PEPCO pipeline) is compared with hypothetical variations on that spill with different responses, there are other options. One methodology involves taking the reported “actual” costs and estimating how much less (or more) the costs might have been had different response actions been taken in the response. The more detailed the information on the original actual costs are, the more accurate this methodology might be. The reason for this is that the changes in the trajectory, fate, and effects of the oil will change different components of the spill response costs. For example, if shoreline oiling is decreased, shoreline cleanup operations may be less expensive because fewer personnel, equipment, and oiled-debris disposal will be required.

Costs for shoreline cleanup by shoreline type and degree of oiling have been modeled (Etkin, D.S., 2001b and 2003). If the reduced shoreline cleanup is the result of more on-water oil recovery, the costs for on-water recovery would also have to be adjusted. Generally, the amount of removal equipment and associated personnel would not have changed with increased efficiency in removal, but the disposal costs for the greater amount of oil recovered would have increased. A more efficient and shorter oil response operation would also reduce the overall

monitoring and logistics costs, but it would not change the amount of the initial mobilization costs. If the equipment and personnel have arrived on-scene, there will be costs regardless of whether the equipment is used or how efficient the response operations are in removing oil from the environment.

In this study, the actual reported costs for the T/B BOUCHARD 155 and T/V COMMAND were adjusted to reflect reduced shoreline oiling and differences in oil removal. The potential inaccuracy in this approach is that it relies on the initial reported spill response costs including only those cost categories that are legitimately spill response costs as listed earlier and not including restoration costs, vessel salvage and repair, or other RP costs not associated with oil removal from the impacted environment. In the case of the PEPCO spill for which detailed information is available on actual costs, adjustments were made to remove non-response related costs.

Natural Resource Damage Assessment Calculations

For the BOUCHARD case, the NRD costs were based on the settlement, which included negotiated restoration project costs and government assessment costs. For that case, most of the NRD costs were related to recreational beach use loss, which is proportional to shoreline oiling. Thus, for the alternative response scenarios, the proportionate change in NRD cost from the NF case could be calculated from the percent change in volume of oil that came ashore.

For the other spills examined, the NRD costs were not based on the settlements, as the change in the NRD costs with change in impact could not be quantified from the information available. Rather NRD costs were calculated based on compensatory habitat restoration of a scale that would replace model-estimated biological injury losses using methods employed by natural resource trustees under OPA90 regulations.

The NRD costs for biological impacts were modeled as estimated costs to restore equivalent resources and/or ecological services. This is the preferred method used by federal and state natural resource trustees, based on guidance in the OPA90 regulations. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat (salt marsh) restoration for NRD compensation of injuries to wildlife, fish, and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish and invertebrates, and equivalency is assumed if equal production of similar species (that is, the same general taxonomic group and trophic level) results.

Socioeconomic Costs

An oil spill can have serious socioeconomic impacts on the affected region, local communities, residents, the state, and the Federal Government. These impacts include damages to real and personal property, loss of use of natural resources (parks and recreation areas), and loss of income and expenses (fishing, tourism, recreation, shipping and other commerce). As a major shipping port and tourist and recreation area, Puget Sound and the Columbia River are particularly vulnerable to socioeconomic impacts from oil spills. Reduction in tourism, commercial fishing, and blocking the shipping port could have widespread impacts. There can also be serious impacts on the Native American Tribal Nations, particularly with respect to subsistence fishing.

In the case of an oil spill, OPA 90 allows the Federal Government to collect from responsible parties socioeconomic costs including:

- Loss of natural resources (lost use);
- Losses for destruction of real/personal property;
- Losses of subsistence use of natural resources;
- Net loss of taxes/fees/net profit due to injury, destruction/loss of real/personal property or natural resources;
- Loss of profits or earning capacity due to damage to real/personal property or natural resources (for example, fish);
- Governmental costs for providing increased or additional public services during or after removal activities.

In addition to the costs that the federal and state government authorities can collect, there are also possible third-party damage suits that can ensue. Successful damage suits in past oil spill incidents have included payments for:

- Out-of-pocket costs relating to removal of oil or restoration of impacted property;
- Economic losses, including lost revenues and profits due to lost tourism or business opportunities;
- Cost of repair/replacement of physical property damaged by a spill (for example, fishing nets, docks);
- Loss of revenues from decreased fishing resource;
- Increased cost of fishing due to necessity of fishing in different locations;
- Damages to real property, including potential damage to market values of properties "stigmatized" by an oil spill;
- Possible replacement of natural resources irretrievably oiled by the creation of new natural resources;
- Losses by sport fishermen incurred as result of curtailment of fishing;
- Subsistence losses to American Natives.

The socioeconomic costs are based on the real and perceived impacts, which are related to the degree of oiling, oil type and persistence, the degree to which cleanup operations can mitigate the oil impacts, and the time of the impact.

There are also potential socioeconomic impacts that go beyond the specific categories listed above. The long-term rippling effects on a local economy after a large or catastrophic oil spill are difficult to measure. There are important impacts that oil spills might have, such as those that impact longer-term quality of life, psychological impacts, and spiritual values. These impacts have been described anecdotally for other oil spills, particularly the Exxon Valdez oil spill (Fall, et al., 2001, and Russell, et al., 2001).

When comparing different response scenarios and their potential impacts on socioeconomic costs, there are some cost components that will be affected and others that will not. The costs associated with blocking ports and vessel traffic due to response operations will be reduced if there is a faster and more efficient on-water recovery operation, depending on the location of the

spill and local vessel and port activity. Costs for commercial fishing losses will be dependent more on fishing bans imposed by authorities than on actual oiling. If the spread of the oil is more contained, it may mean that the bans would encompass a smaller area. Often, though, fishing bans are imposed because of potential impacts from the oil and not on real measured levels of hydrocarbons in sampled fish. Some aspects of socioeconomic damage, such as those related to tourism, might be due to the specific factors of the spill and general magnitude of the incident rather than to actual damages.

This cost category is clearly the most difficult one to address. There are varying definitions of socioeconomic costs and different categories that are accepted as "legitimate" depending on the particular use of the data, whether for litigation settlements, fines, civil suits, or cost-benefit analyses for regulatory analysis. ERC has done a number of socioeconomic cost analyses, including ones for the U.S. Army Corps of Engineers (Etkin, et al., 2002 and 2003) and Washington Department of Ecology (Etkin, et al., 2005). In each case, the government economists had different perspectives on socioeconomic costs, including acceptable estimation methodologies and necessary categories of costs to include.

Since there was very little reliable information available on socioeconomic costs available for the spills modeled for this study, this category of costs is presented in a qualitative rather than quantitative manner. That is, the way in which changes in oil fate based on differences in spill response might affect costs is mentioned only qualitatively.

Significance of Differences in Impacts with Alternative Response Scenarios

The use of modeling to simulate hypothetical spill scenarios introduces certain degrees of inherent variability and "randomness" that may impact the results and outcomes. Because the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability ("noise") in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This phenomenon results in variation in the specific water areas and shoreline locations oiled and, in some cases, the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

Because the differences in amounts of oil removed are small in the simulations, the differences between runs are, in many cases, less than the randomized variability in the model and are not significant. The randomization is proportional to the turbulent energy level of the system. Thus, the randomized variability is much higher in a place like the Strait of Juan de Fuca where turbulence and currents are high, and relatively low in Florida waters in the summer (that is, the BOUCHARD case). This means that the differences between model runs, where the change in the response is subtle, may not be measurable (significant) in one spill (for example, the Strait of Juan de Fuca spill) but may become apparent in model results for another spill (for example, the BOUCHARD case). These considerations should be kept in mind when interpreting the model results.

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APPENDIX C.

ASSUMPTIONS ASSOCIATED WITH IMPLEMENTING AN LF CAPABILITY

Acquisition Costs

Complete USCG system acquisition costs for Options 1 and 2 are estimated from the literature and cost estimates from system developers. Lissauer and Robe (2005) estimated the cost of components in implementing an LF sensor capability in an integrated multi-sensor oil spill surveillance system at $600–900K. The acquisition costs for the three systems tested at OHMSETT are somewhat lower with the $200K–300K estimate for the NASA POC and the $500K estimate for the LDI^3 FLS-AM system (as per Table 21 in Section 6.3).

Accordingly, a sensor system acquisition cost of $300K to $500K will be adopted for Option 1, which includes the cost of the basic system itself. For Options 2 and 4, the acquisition cost for the UBTL system ($150K as per Table 21 in Section 6.3) will be used. To arrive at an annual cost reflecting this up-front acquisition cost, the life-cycle duration of the system is assumed to be ten years. This produces an annualized acquisition cost estimate for Option 1 of $30K to $50K per year per system ($300–$500K over ten years), and $15K per year per system for Options 2 and 4 ($150K over ten years).

For Option 3, the acquisition cost is the annual contract fee for having the sensor available to the USCG. The estimated cost for a NASA contracted LF sensor deployment involving a commercial aircraft with NASA/EG&G engineers and analysts over a period of two days is $32K. This representative deployment involves transit from Wallops Island to Cape Cod (CGAS Cape Cod) and three surveys each of 5-hour duration. If this is multiplied by five to reflect the projected ten-day deployment in a year, an acquisition cost of $156K per year, or $1.56M over ten years, is produced.

To this should be added an annual maintenance service fee (maintenance to be provided by EG&G) of $25K per year. The total NASA interagency contracted acquisition cost for Option 3 then becomes $180K per year per system or $1.8M per system over ten years. (This compares favorably with an estimate for providing the LDI^3 FLS system to the USCG on a Turnkey Service Basis for $10K per day or $100K per ten days in a year. When aircraft charges are added to this (approximately $10K per day or $100K per ten days), a total estimate of $200K per year is produced. It should be noted that although this is much higher than the estimated system acquisition costs for Options 1, 2 and 4, it is an all-inclusive charge with all of the other implementations costs (installation, personnel, training and maintenance) fully accounted for.

System Integration and Installation Costs

System integration and installation costs are somewhat more difficult to estimate because they depend heavily on the nature of the LF system acquired and the aircraft that the system is installed aboard. Retrofitting a USCG aircraft for Option 1 (integration and installation of the LF sensor into an existing multi-sensor surveillance system aboard a fixed-wing aircraft) will undoubtedly require considerable design, certification and aircraft fabrication. Conversations

with USCG aviation personnel indicate that a cost of $50K–100K per aircraft is not unreasonable. This produces an integration/installation cost figure of $ 5K to $10K per year per platform.

To obtain a more accurate picture of installations costs for a representative LF system, an estimate of installation costs for installing the Canadian SLEAF system in an HC-130 and HH-60 Jayhawk helicopter was obtained from MTC Technologies (2006). For the HC-130, the installation costs were $192,500 for non-recurring engineering and certification costs and $116,910 for actual installation in each aircraft. For Option 1, assuming installation in three HC-130 aircraft, this produces an installation cost of approximately $181K per aircraft over 10 years (or $18K per aircraft per year).

For the HH-60, the installation costs were $166,125 for non-recurring engineering and certification costs and $86,945 for actual installation in each aircraft. For Option 2, assuming installation in ten helicopters, this produces an installation cost of approximately $104K per aircraft (or $10K per aircraft per year).

For Option 4, either installation in an existing port or door-mount arrangement on a helicopter or small fixed-wing aircraft would be required such that installation costs would be minimal, with installation engineered on-scene. For each system/aircraft combination, a one-time installation cost of $10–15K per platform ($1.0–1.5K per year per platform) is assumed. This estimate is based on conversations with NASA/EG&G Wallops Island (NASA/EG&G, 2006) indicating that it costs $10–15K to install mounting hardware for the NASA POC LIDAR in a de Havilland Twin Otter.

For Option 3, the system integration cost is included in the acquisition cost.

Airborne Platform Costs

Airborne platform costs for USCG aircraft for Options 1 and 2 are taken directly from Commandant Instruction 7310.1J dated March 15, 2006 (USCG, 2006) which gives standard cost-reimbursement rates for USCG cutters, aircraft and personnel. These rates are given on an hourly basis. For purposes of airborne platform costs, a usage rate of eight hours per day, or 80 hours during a ten-day deployment period to support oil spill response operations is assumed. It should be noted that the airborne platform cost figure is not multiplied by the number of systems, because it is assumed that only one platform (the one closest to the spill) would respond. If more than one responded, it is assumed that only one would be airborne at a given time. However, the actual deployment scheme during a response could change at the discretion of the On-Scene Coordinator, increasing the airborne platform costs.

For the HC-130 aircraft (Option 1), this translates to an estimated airborne platform cost of $11,266 per hour or $933K per year. However, since the aircraft is also providing a platform for the other sensor systems, only a portion of the cost should be associated with the LF sensor capability, not to mention the fact that the aircraft is also providing a platform for visual observations. Accordingly, an airborne platform cost of $200K per year for Option 1 (approximately 20 percent of the total platform cost) is assumed.

For the HH60 helicopter (Option 2), the platform cost per hour is $8,905 or $712K per year per platform. Again and adjustment must be made to account for the fact that the helicopter provides a platform for visual observations and possibly a FLIR. Accordingly, an airborne platform cost of $180K per year is adopted for Option 2 (approximately 25 percent of the total platform cost). It should be noted that this cost is not being multiplied by ten, because it is assumed that only one of the pre-designated helicopters would be used to support the ten-day response operation. However, there is no reason that a second LF system and helicopter could not be utilized on the same spill.

For Option 3, the airborne platform costs are included in the acquisition costs. For Option 4, an airborne platform cost of $8K–$10K per day is assumed. This amounts to an airborne platform cost of $80K–$100K per year for a ten-day deployment. (This is consistent with aircraft leasing rates provided by NASA Wallops Island for deploying the POC system.)

Recurring Maintenance Costs

Annual maintenance costs will depend on the complexity of the LF sensor system being implemented. NASA/EG&G (Edgerton, Germeshausen and Grier Engineers) (2006) has quoted an annual maintenance cost of $25,000K per system for their POC system. This amounts to approximately ten percent of the total system acquisition cost for the NASA POC specified in Table 21 in Section 6.3. This gives an annual recurring maintenance cost estimate for the Option 1 system of $25K per system per year. If the same relationship is assumed for the UBTL system, this produces an annual maintenance cost of $15K per year per system for Options 2 and 4. For Option 3, the recurring maintenance costs are absorbed in the annual service acquisition cost.

Operating Personnel Costs

Operating personnel costs address the manpower associated with operation and maintenance of the LF sensor system only. It does not include the cost of the platform aircrew, which is already included in the airborne platform costs estimated in Section 6.4. However, estimation of this cost component is complicated by the fact that it depends heavily on the complexity of the system and the number of personnel required to support the system. Specific assumptions must be made as to which USCG unit supports and operates the system. Decisions on these issues will probably not be fully addressed until a specific LF sensor system has been identified, and a specific implementation option is chosen. Accordingly, the following estimates require some conjecturing and are truly rough estimates. Once the personnel involved are specified, then the costs are computed using the hourly rates published in COMDTINST 7310.1J (USCG, 2006).

For Option 1, it is assumed that the LF system is maintained and operated by two aircrew personnel at the E-6 ($46 per hour) and E-5 ($40 per hour) levels for each system. Their involvement with the system involves 80 hours per year of actual operational flight time (including response time and in-flight training time) and a corresponding 80 hours per year maintaining the system and training for its operation on the ground. This produces a personnel investment of $7,360 + $6,400 = $13,760 or approximately $14K per year per system for Option 1.

For Option 2 and Option 4, it is assumed that each system is operated and maintained by E-5s (possibly members of the NSF Strike Teams). This produces a personnel investment of approximately 160 hours X $40 per hour = $6K per year per system. For Option 3, the operating

personnel costs are included in the contract service acquisition costs. This amounts to an airborne platform cost of $80K–$100K per year for a ten-day deployment.

Training Costs

Training for the LF systems is envisioned as a one-week training course for each individual involved in operating the system. Because each member is probably assigned to the system for a period of 2-3 years, it is assumed that over a ten-year period, eight individuals will require training to operate each of the systems in Option 1. If the course, provided by the system manufacturer costs $5K, then the training course cost per system is $40K per 10-year system life-cycle, or $4K per system per year for Option 1. For Options 2 and 4, the costs are assumed to be approximately half that for Option 1, or $2K per system per year. For option 3, the training course costs are included in the contract service acquisition costs.

Another training cost involved in ensuring that the LF sensor capability is maintained is aircraft time for annual familiarization and refresher training. Some of this training can be accomplished in the course of general flight crew training; however, it is assumed that two days of dedicated training (16 hours) per LF sensor system will be needed on an annual basis. This produces an annual airborne platform cost for training of $40K per year per system for Option 1, $36K per year per system for Option 2, and $20K per year per system for Option 4. No cost is associated with Option 3.

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